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04a HUMAN FACTORS EVALUATION OF THE ARGUS (CP-107) AIRCRAFT (U)

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ABSTRACT

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A human factors evaluation of the Argus (CP-107) aircraft was carried out during three Northern Patrols totalling 49.3 hours. About 180 adverse comments on the human engineering of flight and tactical crewstations are listed in detail. Measured noise levels at the Radio Operator's ear are shown to be potentially hazardous to hearing. Calculations show that active sonar returns of up to at least 70 dB SPL will be masked by the aircraft noise. Similarly, auditory processing of transient passive sonar information will be impaired. General habitability is seen to be grossly inadequate for the aircraft's present role.

Suggestions are advanced for short- and long-term measures which might be adopted to improve comfort and operational efficiency.

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HUMAN FACTORS EVALUATION OF THE ARGUS (CP–107) AIRCRAFT (U)

SUMMARY

At the request of the Director Equipment and Readiness Maritime Air, a human factors evaluation of the Argus (CP–107) aircraft was carried out, to assess effects on crew comfort and operational efficiency, should the aircraft be continued in its present role without modification for a further period of 10–15 years.

The crew of one Argus aircraft were observed during a routine Northern Patrol totalling 49.3 hours, scheduled into three flights of approximately equal duration. Operational and environmental factors were subdivided for attention by the four investigators who report the following findings:

NOISE AND VIBRATION

The outstanding feature of the aircraft is its high noise level. At high engine speeds (2320 rpm) the overall sound pressure levels range from 113 dB in areas close to the plane of propeller rotation, to 104–109 dB in the Tactical Compartment and ASW Stores Launcher Area. An impairment of communication efficiency would therefore be expected during takeoff and tactical operations. The noise is predominantly low frequency and cannot be effectively reduced by practicable sound-treatment procedures. However, the risk of hearing impairment is minimal for crew members who wear effective hearing protection and work away from areas of maximum noise. The Radio Operator is located in the worst possible area of the aircraft. Noise masking here is such that the receiver amplifier gain has to be set to a very high level in order to hear incoming signals. The resulting receiver noise, combined with aircraft noise, produces noise levels under the flight helmet earphones which are potentially hazardous to hearing, in the long term. Ideally the Radio Operator should be relocated in a less noisy area. Alternatively, the noise hazard could be reduced immediately by wearing properly fitted earplugs under the helmet. This could also improve the intelligibility of received speech by reducing speech plus noise level below the overload region of the auditory system.

The moderately high levels of vibration which occur in structures close to the aircraft engines should be reduced by the application of suitable isolators.

MASKING OF SONAR SIGNALS

The intense low-frequency energy coming from the aircraft engines will mask most active sonar returns that are less than 70 dB SPL and many that are as much as 80 dB. It would be very difficult to reduce the low-frequency energy reaching the observer's ears, short of fitting the aircraft with jet engines. However, a substantial improvement in the detection threshold (about 20 dB) could be gained by increasing the display frequency of the sonar returns to 1850 Hz from the 850 Hz now used.

In addition, engine noise adversely affects auditory processing of transient passive sonar information, since it almost completely masks sound below 500 Hz, where most ship and submarine sounds occur. This is a less serious problem than the masking of active sonar returns, since the passive sonar task is primarily visual.

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HUMAN ENGINEERING OF CREWSTATIONS

There is a problem of seating discomfort throughout the aircraft. Only the Pilots can make substantial use of the seat backrest and, even here, the headrest projects too far forward when the flight helmet is worn. Attention should be given to designing seats which are appropriate to the postures demanded by the various tasks carried out at the different crewstations.

Only the Pilots and Flight Engineer have workstations which reflect a reasonably acceptable level of human engineering. The Routine and Tactical Navigators' stations are outstandingly bad. The layout of displays and controls is unrelated to the operational sequences in which they are used. This imposes an unduly high scanning, mental and manual load on the navigators and unnecessarily increases the risk of error during critical manoeuvres, and when the crew are tired. The Radar, Radio and ECM Operators have less severe interface problems (apart from those resulting from the high level of aircraft noise), but their stations fall well below modern standards of human engineering design. Jezebel, MAD and Julie Operators have relatively minor interface problems, although there is still considerable scope for improvement.

Small gains in comfort and efficiency could be obtained by removing redundant displays and controls and relocating the more distant components at each station within easier reach.

The resulting reduction in gross head and eye movements should have a beneficial effect on the high incidence of motion sickness reported in earlier studies of the aircraft. However, most operators will still be faced with a variety of scattered, bulky equipment which cannot be acceptably laid out around the seating position. Additional gains could be made only by a complete redesign of each station using human engineering criteria. It is concluded, however, that a redesign exercise of this kind is unlikely to be cost-effective with the present aircraft and its associated hardware.

HABITABILITY AND CREW FATIGUE

The most urgent requirement is for a commercial aircraft-type lavatory to replace the existing hazardous arrangements for human waste disposal. Another prime requirement is for improved rest-space facilities and elimination of the need to sleep on make-shift beds in the ASW Stores Launcher Area. Heat distribution should be improved, to reduce the present high vertical temperature gradient from feet to head, which may range up to 50 degrees (F) in some locations. The capability of the galley facilities should also be increased, in order to cater adequately for the number of crew normally carried on routinely prolonged flights.

Attention should be given to the possible redesign of flight-scheduling so that adequate sleep can be taken before a flight and so that there is minimal disruption of the crew's normal circadian rhythms of physiological activity. Greater serviceability of the aircraft would minimize the present frequent delays, which contribute to fatigue produced by the long working hours of Argus crews, and would do much to maintain the existing high level of morale.

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I. INTRODUCTION

OBJECTIVE

At the request of the Canadian Forces Headquarters, Director Equipment and Readiness Maritime Air, a human factors evaluation of the Argus (CP–107) aircraft was carried out to assess effects on crew comfort and operational efficiency should the aircraft be continued in its present role, without modification, for a further period of 10 to 15 years.

METHOD

The crew of one Argus aircraft were observed during a routine Northern Patrol totalling 49.3 hrs, scheduled into three flights as shown in Appendix A. The ages and considerable flying experience of the 15 individual crew members are shown in Appendix B.

A plan view of the aircraft is shown in Appendix C. This illustrates the layout of the crew-stations referred to in later sections of this report. (The sound pressure levels shown on this diagram relate to measurements described in Section III.)

The investigation was extensive, rather than intensive. A wide range of task and environmental variables was studied by the four members of the investigating team, who subdivided these variables as follows:

Dr. I.D. Brown evaluated the human engineering of interfaces between the crew and equipment at their various crewstations.

Mr. S.E. Forshaw measured noise and vibration levels at each crewstation and at various other positions within the aircraft, tested speech intelligibility using the intercommunication system, and carried out an audiometric check on the crew in order to assess long-term hearing risk.

Dr. R.D. Patterson made tape recordings of the aircraft noise at the Sonar Operator's position and of the electrical noise on the communication lines. The recordings were used to assess the effects of these noises on the detection of sonar signals in subsequent laboratory studies.

Maj. J.R. Hodgkinson M.D. carried out an atmospheric check of temperature, humidity and toxic substances, assessed standards of hygiene and sanitation facilities, investigated work-rest patterns among the crew and rest facilities on the aircraft, and noted overt expressions of clinical illness and physiological incidents during the three flights.

In Sections II to V the procedures and findings of the individual investigators are presented in detail and their separate conclusions and recommendations are listed.

In section VI these conclusions are integrated in order to formulate general recommendations for improving crew comfort and efficiency in relation to the aircraft's present operational roles.

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II. A HUMAN FACTORS ASSESSMENT OF CREW/STATION INTERFACES

by I.D. Brown

OBJECTIVES

The main objective of this investigation was to study the man/equipment interfaces at each crewstation in the aircraft, in order to assess the effects on comfort and operational efficiency of seating, display and control design.

A subsidiary objective was to assess the way in which environmental factors, flight-safety measures, and personal equipment, might interact with crewstation design to degrade comfort and operational efficiency.

METHOD

Objective measurement of performance was precluded by the short overall time-scale of the study and by the difficulty of simulating operational conditions such that valid behavioural measures might be obtained. These would, in any case, have been of limited value if obtained from the one crew made available for the study.

Interface difficulties were therefore assessed subjectively. This assessment took two forms:

1. Collection of data from crewmembers by means of a standardized questionnaire (see Appendix D). This was adapted by DCIEM as a general-purpose instrument for human factors evaluations of Canadian Forces aircraft. For the present purpose it was modified to include questions on lookout positions and the ASW Stores Launcher Area of the Argus aircraft.

2. A study of each crewstation by the author, using established human engineering criteria to evalute display and control design, and the general layout of each workspace.

PROCEDURE

The first flight was spent in establishing rapport with the crew, becoming familiar with the disposition of crewstations and the way in which the crew rotated among the stations, distributing questionnaires to a few selected crew members, and studying some crewstations in detail. The second flight was spent in distributing the remaining questionnaires, categorizing comments as they were returned, and studying the remaining crewstations in detail. Photographs were also taken of selected crewstations.

The third flight was spent in summarizing comments from the different groups among the crew and checking the validity of each comment by personal observation.

Each man completed a separate questionnaire for each of the crewstations he would normally be expected to fill, in rotation, during an operational flight. Appendix E details the distribution of these stations among the crew. Thus the two Flight Engineers and the three Pilots were asked to complete one questionnaire each, the four Navigators four each, and the six Observers six each.

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RESULTS

Questionnaires were analyzed by noting the frequency with which comments were repeated among the relevant crew group. These pooled comments were then categorized according to whether they related to displays, controls, general work-space design, environmental factors, or personal equipment, at the crewstation in question. Within each category, comments were listed in an order which derived partly from frequency of report in the questionnaire returns and partly from the importance of the comment for operational efficiency (as assessed by the author). In this way, it was hoped to establish an intelligible pattern of reporting the wide-ranging comments obtained from this extremely small group of questionnaire respondents.

In the remainder of this section, specific comments will be listed for each crewstation, in turn, showing in brackets the number of respondents returning each comment on the questionnaire. At the end of each list of specific comments, a general evaluation of the crewstation will be given from a human engineering viewpoint. Finally some recommendations will be made for short- and long-term improvements in the station.

Flight Engineer

Displays

1. The red panel-lighting causes eye-strain and induces fatigue. Use individual instrument lighting in white, with dimming control. (1)
2. The ac/dc power-failure warning lights are incorrectly positioned. The upper should indicate dc failure and the lower ac failure. (1)
3. The cabin-heater gauge, cabin-heater standby/normal selector and the cabin-heater overheat warning light should be grouped with the cabin-heater temperature controls. (1)

Workspace

1. The seat is hard and uncomfortable. (1)

Environment

1. Noise and vibration levels are high and induce early fatigue. (1)
2. Heat distribution is uneven, leading to a hot head and cold feet. (1)

Personal Equipment

1. The Gentex helmet is uncomfortable. (1)

General Summary

Grouping of major displays is fairly good, but the enormous quantity of displayed information has necessitated undue enlargement of the console and reduction in size of some individual instruments. The former produces a requirement for gross head and eye movements in order to monitor displays adequately. These gross head movements, and the head-down working posture, are largely responsible for complaints of discomfort when wearing the Gentex helmet for long periods. The small size of some displays, leading to discrimination problems, is a major factor in complaints of poor illumination.

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Many controls are beyond normal reach, particularly those on the overhead panel, and the throttles are badly positioned to the left. The intercommunication control panel below the work-surface on the left protrudes into the space required for individual seat adjustment and tends to impose a twisted posture on the Flight Engineer, which would be expected to induce fatigue and increase the difficulty of monitoring right-hand displays.

Recommendations

Short-term improvements in comfort and efficiency could readily be made by attention to the seating and illumination problems, by repositioning the intercommunication control panel above the work-surface, by reversing the positions of some displays (e.g., the ac/dc power failure warning) to achieve a more compatible spatial layout, and by grouping together all displays and controls which relate to the same operational function (e.g., cabin heating).

Long-term improvements should basically aim at a substantial reduction in size of the console to improve visual scanning and reach to the farthermost controls, and a redesign of the seat to suit the essentially monitoring function at this station. Important displays and controls should be centralized and grouped by function with colour-coding used to delineate these functionally similar areas of the console. Individual instruments need redesigning to suit their dual purpose:

(a) to provide quantitative information on the state of certain functions (e.g., engine torque) and

(b) to provide quick check readings on comparability of information from individual displays (e.g., r.p.m. on the four engines). The recommendations made by Beldam and Lewis (1959) for improving warning of system failures would reduce the risk of overlooking a fault during prolonged monitoring.

These long-term aims could be achieved satisfactorily only by a detailed human factors study of the Flight Engineer's operational function.

Pilot

Displays

1. The radar altimeter is positioned outside the display area normally scanned. (2)
2. The standby artificial horizon is also outside the normally scanned area. (1)
3. An accurate compass reading on TACAN BME is difficult to obtain at night, because it is positioned outside the normally scanned area and the ADF pointers sometime obscure the read-out. (1)
4. The Pilot's and Co-pilot's artificial horizons are driven from one gyroscope. Malfunctioning would be dangerous for low-flying at night in the absence of a real horizon. (1)
5. Preference is expressed for HSI, combining ILS, ADF, VOC Bearings and glide-path and close course indicator, and TACAN readout on one instrument. (1)

Controls

1. Pilots of below average height have difficulty in reaching the throttles when the safety harness is correctly tensioned and the aircraft is on maximum power. They must rely on good intercommunications with the Flight Engineer if an emergency occurs during take-off. (1)
2. The ADI switches on the overhead consoles pertain to engine state and have to be manipulated at a critical phase of flight. They should be moved to the Flight Engineer's station. (1)

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3. The auto-pilot "on" switch should not be guarded, as it is used for flight-safety. (1)
4. The undercarriage and flap selectors can easily be kicked when changing position. (1)
5. The landing-light switch can easily be knocked on accidentally. (1)

Workspace

1. The seats are uncomfortable and often have a badly positioned headrest. (1)
2. Better storage facilities are needed for publications. (1)
3. The check-list holder and light should be removed. (1)

Environment

1. The high noise level during take-off, plus the poor intercommunications ISHF and VHF interlace, causes communication difficulties which can be overcome only be absolute intercommunication discipline. (2)
2. Cabin temperature is difficult to control. (1)

Personal Equipment

1. The flight suit is too hot for southern climates. (2)
2. The life-vest is hot and uncomfortable. The Navy jacket-type would be preferred. (1)
3. The helmet is uncomfortable. (1)

General Summary

The high noise level is obviously causing communication difficulties at certain critical phases of flight (see Section III). Three fairly important instruments are outside the normally scanned field of view and should be repositioned. Some controls (e.g., ADI switches) should be moved to the Flight Engineer's station to unload the Pilot. Other controls (e.g., undercarriage and flap selectors) should be redesigned to prevent accidental operation. Otherwise, this station seems relatively acceptable. There is a flight-safety problem with the single gyroscope driving both artificial horizons. The complaints of discomfort with personal equipment, seating and with inadequate temperature control should receive attention. Discomfort of this kind on long-range patrols will intrude upon consciousness to the extent of becoming a potential source of distraction from the main task of piloting the aircraft. The poor matching between the Gentex helmet and the head-rest of the seat, illustrated in Figure 1, is almost certainly a major cause of physiological fatigue reported at this station.

Recommendations

Short-term improvements in comfort could readily be obtained by increasing the range of seat adjustment and by repositioning the seat headrest, by increasing intelligibility of intercommunication speech and by providing more adequate storage facilities. Clothing and life-vests more suited to the operational demands on the Pilot should be provided. Better control of cabin temperature and ventilation would also improve comfort and, probably, performance. Repositioning the scattered displays within the normally scanned area would substantially reduce the visual load. Better guarding of some controls would relieve anxiety about their accidental operation.

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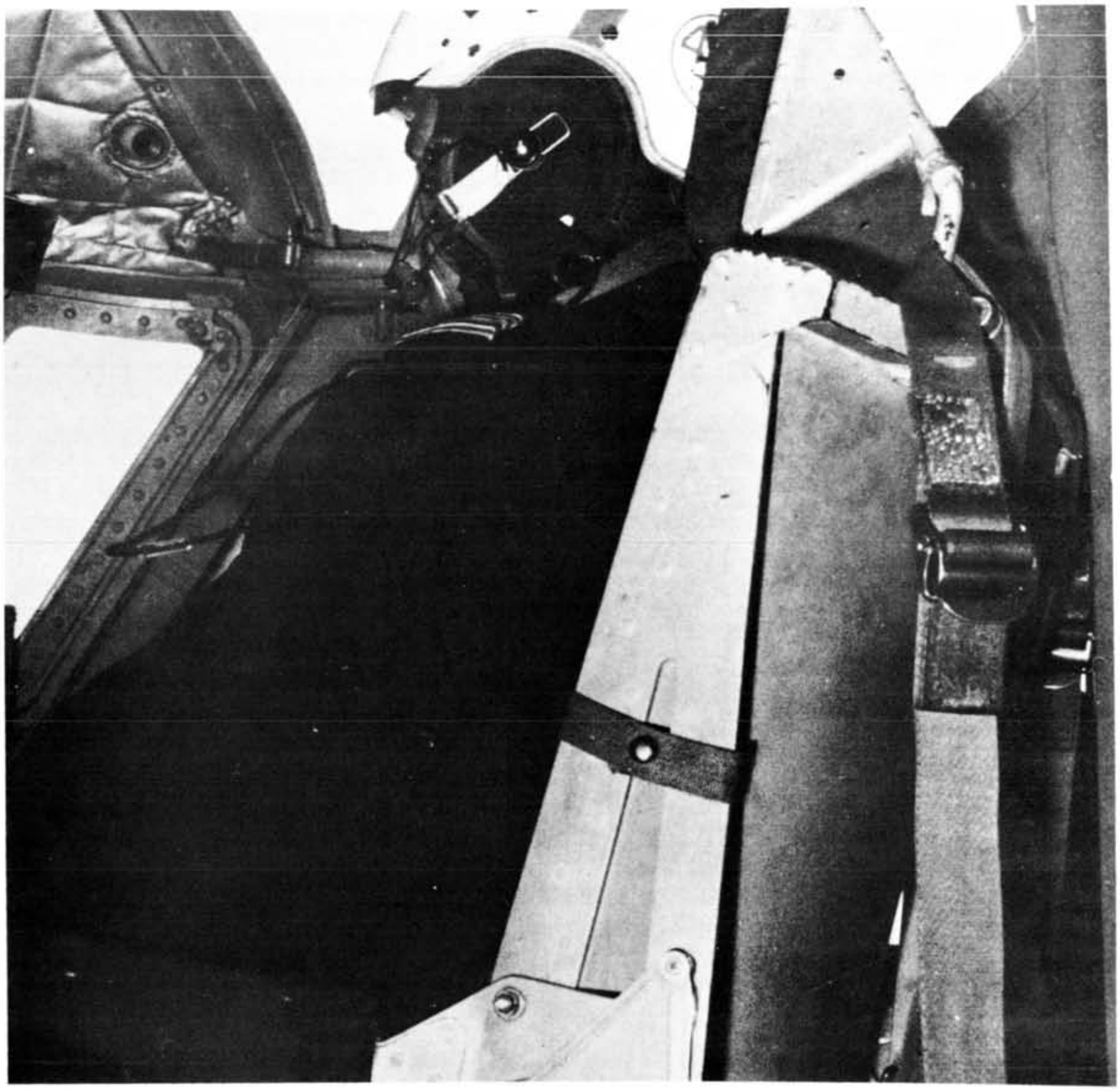

Figure 1. Flight helmet and headrest combine to impose a head-forward posture at the pilot's station.

Long-term improvements would require a far more detailed human factors investigation of the Pilot's operational functions than was possible in this brief study. However, it is almost certain that, in addition to the short-term improvements listed above, it would be necessary to update the design of individual instruments and controls, group them by function, redesign their spatial layout according to importance and frequency of use and, particularly, ensure that they were located within an easily scanned area and within easy reach.

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Routine Navigator

Displays

1. TACAN readout is required here, rather than at the Tactical Navigator's station, to eliminate dependence on the Pilot for relay of range and heading. (3)
2. The LORAN RX counters are difficult to read, because of poor positioning. (1)
3. The main instrument panel is too vertical for comfortable read-out of displayed information. (2)
4. The lamp produces glare on dials and charts, and obscures some displays. (2)
5. The MDC has pointers which are too broad for its scale, making interpolation difficult. (2)
6. The drift guage is not illuminated. (1)
7. The ADF tuner scale is too small. (1)
8. The existing gyroscopes are not suited to the aircraft's role. Drift has to be checked by climbing "above the weather" occasionally. (1)

Controls

1. The latitude/longitude correctors are too distant and not illuminated. (2)
2. There are far too many "press to test" warning lamps. (2)
3. Grouping of equipment by function is poor; e.g., the compass control unit, latitude correctors. (1)
4. The drift gauge is inaccessible. (1)
5. The ANTAC/Doppler Isolate switch could be operated by accident, as could the MDC compass between MAC and DC. (2)

Workspace

1. The sextant step is inconvenient to use, and obstructive. (4)
2. The seat is difficult to adjust on its runners, it is uncomfortable, and it is not stressed for take-off. (2)
3. The LORAN set is inaccessible for smaller men when seated. (1)

Environment

1. Heat distribution is poor, providing a hot head and cold feet. (3)
2. Noise and vibration levels in the galley are far too high (a position forced on the navigator at takeoff and landing because his seat is not stressed for these phases of flight). (2)
3. The adjacent cabin heater has no safety cover. (1)

Personal Equipment

1. The Gentex helmet causes discomfort and it catches in overhead cables. (2)
2. The life-vest is hot and uncomfortable. The Navy type would be preferred. (2)
3. The flight suit is too hot for southern climates. (1)
4. Some desirable items of the Arctic kit are not available, e.g., mukluks, liners, sweaters. (1)

[redacted]

[redacted]

General Summary

This station is generally regarded as unsatisfactory. Comfort is minimal with respect to noise, vibration, temperature and ventilation. The seat is uncomfortable and inadequately stressed, forcing the Navigator to sit in the galley (an even more noisy and vibrating position) during take-off and landing. The sextant can be read only by moving to an unsatisfactorily designed platform, which partially obstructs access forward. The main console is poorly laid out, the viewing angle is unsatisfactory, the upper displays and controls are inaccessible to smaller men when seated (see Figure 2), and the main source of illumination

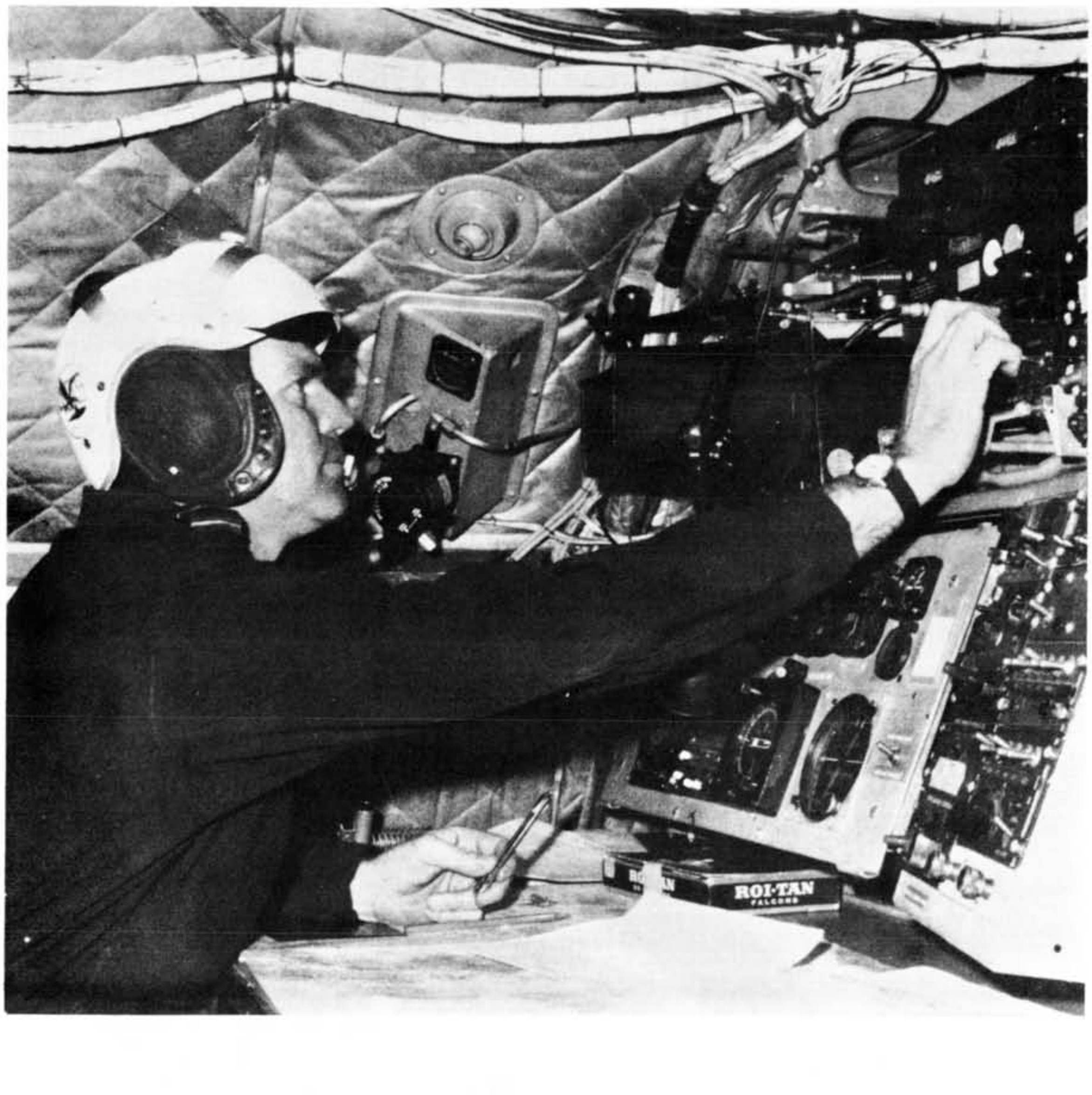

Figure 2. Upper controls are a long reach for smaller men at the routine navigator's station.

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obscures a number of displays (see Figure 3). Legibility of some dials is extremely poor and additional information is required to eliminate dependence on the Pilot or Tactical Navigator. Grouping of equipment by function is substandard, there are far too many manual controls, and some controls are susceptible to accidental switching. The capabilities of the instrumentation do not appear adequately matched to the aircraft's present role. Some personal equipment, particularly the helmet, are sources of discomfort in the Navigator's working posture.

Figure 3. The lamp obscures displays and controls at the tourine navigator's station.

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Recommendations

Short-term improvements are not really the answer to the inadequacies of this station. It would be possible to realign the main displays and controls more closely at right angles to the line of sight, position them within easier reach and provide them with individual, glare-free sources of illumination. However, there would probably be minimal gain from these efforts, unless attention was also given to improvements in seat design and in environmental conditions of noise, vibration and temperature.

Long-term improvements would therefore need to start with attention to these environmental conditions, followed by the design of a comfortable seat, which was stressed for take-off. Consideration should be given to the adoption of a fixed seat height, suitable for taller men, plus the provision of an adjustable footrest. The seat height could then be used as a reference point for redesigning the complete console to provide an adequate horizontal work-surface, at the correct height, and an easily scanned and correctly angled display surface, with all controls within easy reach. A more intensive human factors study of the Navigator's operational functions would be necessary in any redesign of individual instruments and grouping of displays and controls. However, a wealth of highly relevant information is immediately available from Harper and Ostrom's (1952) report on standardizing navigational compartments in multi-engined aircraft. As long as 20 years ago, these authors were reporting many general criticisms of navigators' stations, identical with those listed above. The illogical layout of displays and controls, inadequate lighting, insufficient storage space and unsatisfactory arrangements for celestial sighting, were the more important of these criticisms. Harper and Ostrom's suggestions for design improvements could therefore form a starting point for any long-term remedial measures undertaken at the Argus Navigator's station.

Tactical Navigator (and Co-Ordinator)

Displays

1. The Tactical Display Unit light is inadequate. The table light often has to be dimmed so much, to make the TDU legible, that logs and charts cannot be read. (2)
2. Track reading on the Track/GS repeater is difficult to discern when under time stress, because graduations are unmarked. (3)
3. The Grid Co-ordinate Indicator occupies an important central position, but is seldom used. (1)
4. The new active sonobuoy display is hidden behind the table lights and outside the normally scanned area. (1)
5. The torpedo battery lights are also obscured by the table lamp. (1)
6. Some dials have no illumination. (1)
7. A number of instruments are now unused, yet remain on display and occupy valuable space. (1)
8. Warning indication of selected stores should be displayed at this station. (1)
9. Critical check-cards are placed in different positions on different aircraft. (1)
10. A radio altimeter would be invaluable at this station. (1)

Controls

1. Navigational and stores-release controls are badly positioned to the right. A right-handed Navigator must either drop his plotting instruments in order to operate these controls, or reach over with his left hand, thus obscuring some displays. (4)
2. Labelling of controls is not reliably appropriate to their present function; e.g., the Mk. 30 Heat Switch. (1)

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3. Lighting controls are badly positioned at the far end of the table. (1)
4. The hot-microphone facility is difficult to reach and operate. (3)
5. Too many manual switching operations are required, especially for stores selection. (1)
6. The vertical camera and stores release intervalometers are indexed above the line of sight. (1)

Workspace

1. Layout and grouping of displays and controls are generally very poor. (3)
2. Equipment and rack supports under the aft end of the table restrict leg-room, forcing the two seats together and thus impeding entry and exit to the Tactical Co-ordinator's station. (2)
3. Poor seat design forces both men to adopt incorrect postures. (1)
4. Intercommunication cords become entangled and are difficult to distinguish. (2)

Environment

1. The temperature gradient from head to feet is too great. (2)
2. Noise and vibration levels are too high. (2)

Personal Equipment

1. The helmet is uncomfortable for prolonged use in this head-down position. (1)

General Summary

These extremely important stations clearly have many outstandingly bad human-engineering features. Seating comfort is rudimentary. Displays are scattered, obscured, or otherwise difficult to read out. Illumination is inadequate, labelling of instruments and controls is poorly positioned and sometimes inaccurate. Obsolete components have been retained, needlessly occupying important display areas. Communication with other tactical compartment crew becomes difficult under stress. The heavy manual load imposed on the Tactical Navigator by outdated toggle-switch design and by the unsystematic layout of controls is inexcusable at the present state of the art in human engineering.

Recommendations

<u>Short-term improvements</u> in comfort and performance would undoubtedly follow if the present environmental conditions of temperature, noise and vibration were improved and if the seating positions were adequately spaced. Obsolete equipment should be removed, and console lighting improved. Navigational and stores-release controls should be centralised, to eliminate cross-armed operation. Biased-off switches should replace controls which have a 'select' function, to greatly reduce the number of manual operations required at this station. Intercommunication cables should be replaced by the 'coiled' or 'reel-in' type, and should be colour-coded to prevent confusion.

<u>Long-term improvements</u> should also aim for a substantial reduction in size of the console. Figure 4 shows that many controls currently lie well outside normal reach, and displays at the extremity of the console cannot be monitored efficiently. As suggested for the Routine Navigator's station, a fixed seat with an adjustable footrest would be advantageous in that the seat height would provide a datum from which to design an adequately sized console, with all display surfaces approximately at right angles to the line of sight and all controls within easy reach. The precise layout of individual and grouped displays and controls, for maximal efficiency, could be determined only by an intensive human factors evaluation

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of the operational functions at these two crew stations. One overall objective should be to reduce the gross head movements currently required at this console, since they undoubtedly contribute to the high incidence of motion sickness reported in an earlier survey of the aircraft (ref. 32)[1]. A prime objective should be to update the hardware required by the Tactical Co-ordinator for receipt and storage of tactical information from other crewstations. Even with improved intercommunication, the aim should be a reduction in auditory load at this station and greater use of integrated CRT-type visual displays.

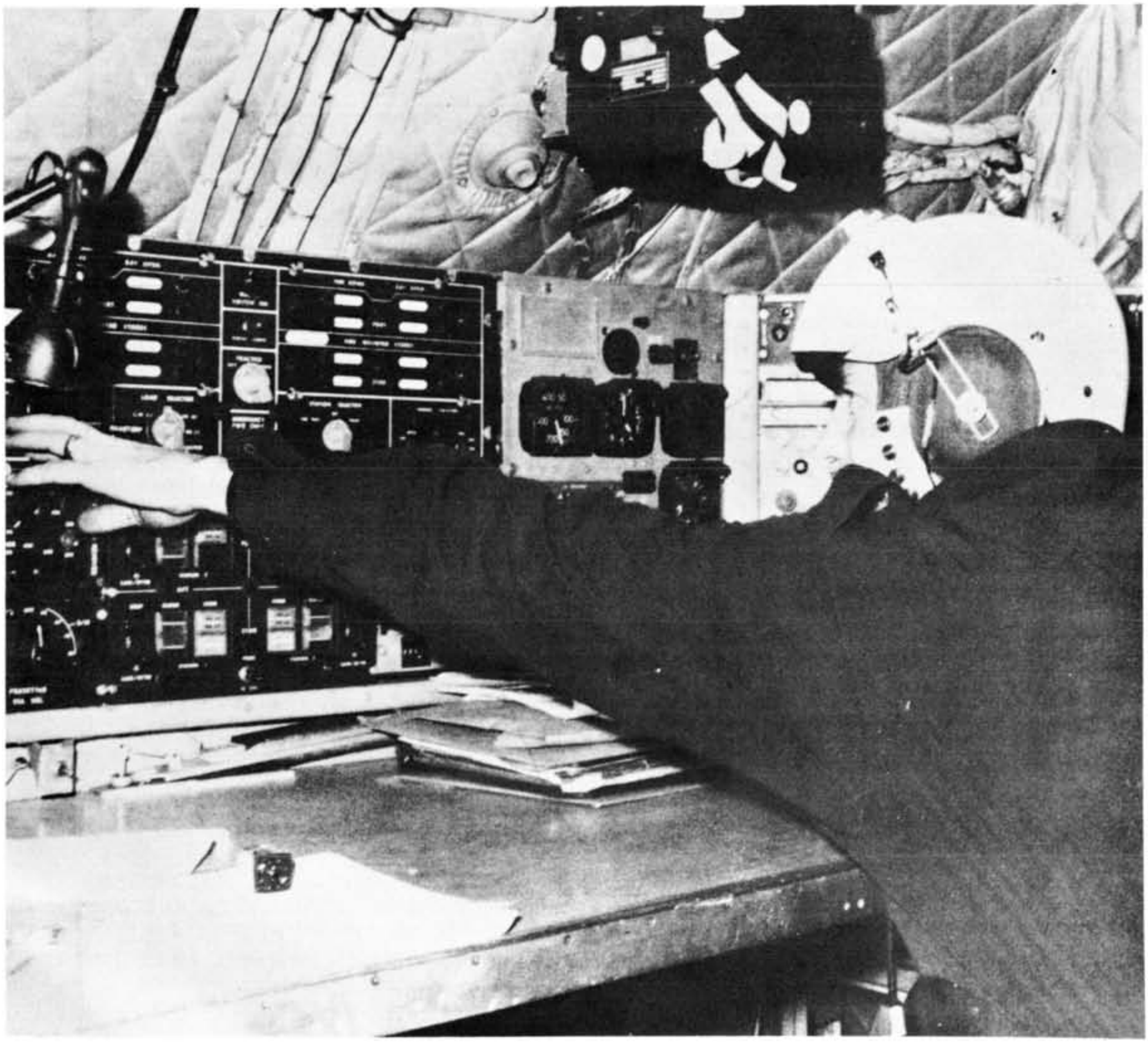

Figure 4. Many controls lie well outside normal reach at the tactical navigator's station.

(1) References 28 through 34 are classified and have been listed separately. If an unclassified version of this report is required, this list (together with the Argus bibliography) will be removed.

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Jezebel Operator

Displays

1. Continuous monitoring of the paper read-out is visually tiring. (1)

Controls

1. Five interlace switches are difficult to reach and should be ganged. (2)
2. The rear lighting control is too distant and several other controls are a stretch for shorter men. (1)
3. Four sonopower switches on the selector boxes of the overhead panel are no longer needed. Several others on the main panel are also obsolete. (1)

Workspace

1. The layout of the station forces the operator to adopt a tiring posture and knee clearance is inadequate. (1)
2. Only four seats are provided for five men on this side of the compartment and a relatively unstable portable chair frequently has to be used at this station. (1)
3. A larger writing surface and a catalogue holder are required. (1)

Environment

1. The continuous burning smell from the paper display is nauseating, especially when combined with the high acceleration forces imposed on the tactical compartment during ASW manouvres. (2)
2. Noise levels are too high for auditory detections when the bomb doors are open. (1)
3. The vibration is disturbing when the aircraft is under full power at low altitudes. (1)
4. The compartment gets too hot in southern climates. (1)

Personal Equipment

1. Sleeves of the flight suit tend to catch on the recorder styli. (1)

General Summary

There are three main criticisms of this station. Firstly, functional changes have been made in the task without removing redundant displays and controls. This redundant hardware occupies valuable space and is potentially a source of confusion. Secondly, a number of controls are too remote from the operator and others impose an unnecessarily high manual load. Thirdly, the seating position is a potential source of fatigue, which is of critical importance for a task such as this, requiring sustained vigilance. The commonly high levels of environmental stress produced by noise, vibration and large temperature differentials are exacerbated by the continuous burning smell and high acceleration forces.

Recommendations

Short-term improvements could be made by removing obsolete hardware, by repositioning the more distant controls within easier reach, and by ganging controls where possible.

Long-term improvements should follow the procedure described for other navigator's stations, i.e., the design of a comfortable seat, preferably of fixed height and incorporating an adjustable foot-rest. Displays and controls could then be laid out optimally, using the seat as a reference point. The high

positioning and reverse slope of the main display should be retained, to assist detection of visual signals. Independent control of ventilation, e.g., by means of a small fan, would eliminate the problem of nauseous smells from the styli, if it was necessary to retain the present recording technique. Any plan for long-term improvements should incorporate the objective of reducing the present high levels of noise and vibration, which are clearly detrimental to detection tasks of this kind (see Section IV).

Radio Operator

Displays

1. The HF2 set is positioned too low to read the dials. (2)
2. The ARC 38 Manual Frequency Selector is alpha coded. (1)

Controls

1. The general layout is poor, because of piecemeal addition of controls. (1)
2. Wide individual differences in volume of intercommunication speech make listening difficult. (1)
3. A take-up reel is needed on the L.F. receiver cord. (1)
4. The presently disconnected TX switch on the HF teleprinter should be wired in for use when HF1 set is switched to data only. (1)

Workspace

1. The station is cramped for space, controls are scattered and poorly laid out, and the layout varies between aircraft. (2)
2. More adequate storage is needed for publications, especially classified documents, and the stowage safe should be moved to a more accessible position. A suitable receptacle is also needed for secure scrap. (3)
3. The teleprinter position is too high and displaced too far to the left for efficient operation. (2)
4. Lighting is inadequate. (1)
5. Table-top space in inadequate. Books and papers sometimes operate the HF TX morse key when the operator is busy. (1)
6. The seating position is uncomfortable and causes armache. (1)

Environment

1. Aircraft, radio and electrical circuit noise are unacceptably high. (4)
2. The temperature differential between head and feet is unduly high. (4)
3. Vibration often shakes papers and instruments off the work-surface. (1)

Personal Equipment

1. Earmuffs in the Gentex helmet provide insufficient attenuation of the high aircraft noise levels and the helmet itself is uncomfortable for prolonged use in this head-down position. (1)
2. The Arctic Kit is inadequate. (1)

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General Summary

There seems general agreement that this is one of the noisier stations in the aircraft and that perfect communication is virtually impossible. The high levels of vibration are also troublesome. The L-shaped horizontal layout of the workspace (see Figure 5) not only extends displays and controls beyond easy reach, but also imposes a tiring posture on the operator (see Figure 6). This condition is exacerbated by inadequate table-top space and stowage facilities, and by the common problem of uneven heat distribution. The scattered layout of displays and controls is a real, though minor irritation, by comparison with the environmental and workspace deficiencies.

Figure 5. Displays and controls extend beyond easy reach at the radio operator's station.

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Figure 6. The L-shaped layout of the radio operator's station imposes a tiring posture.

Recommendations

Short-term improvements might be gained by repositioning the displays and controls within easier reach. In particular, the teleprinter should be brought round into the main console and the HF2 set raised to the level of the HF1. Take-up reels on the intercommunication cords and additional stowage for publications would reduce the clutter at this station. But the lasting value of these improvements would be small if no remedial action were taken against environmental noise and vibration.

Long-term improvements of a substantial nature would be obtainable only by moving this station to a quieter position in the aircraft (see Section III and Appendix 3) and by human engineering the new position in the manner described for the Navigators' stations.

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Radar Operator

Displays

1. Neither scope is angled correctly to the line of sight. The right-hand scope is especially badly positioned and seldom used. (1)

2. Bearing and range markers are inadequately indexed, poorly illuminated and not positioned at eye-level. (4)

Controls

1. Overhead controls are not within easy reach and the Mode 2 IFF is awkwardly located under the table. (3)

2. The Vector Control Unit is badly positioned. The operator has to look away from the scope for so long to set up the VCU that it is seldom used at this station. When it is, the TACHOLD button has to be operated by trial and error, as it is out of sight, and Heading Take-Over could be operated accidentally. (3)

3. The ASV 21 control unit is too distant. (1)

4. The APS 20 controls are too scattered. (2)

5. A more efficient method of passing information to the Tactical Navigator is required. (1)

6. A number of switches are obsolete. (1)

7. The intercommunication cord is too short. (1)

8. Ancillary equipment is too scattered throughout the aircraft. (1)

Workspace

1. The seat is uncomfortable. (1)

2. Table space is inadequate for charts. (1)

Environment

1. The station gets uncomfortably hot when the curtain is closed. (3)

2. Noise levels are high. (2)

3. Vibration causes instruments and papers to fall off the table. (2)

Personal Equipment

1. The Gentex helmet is uncomfortable for prolonged use. (1)

2. The one-piece flight suit makes it difficult to maintain a comfortable temperature in the uneven heating distribution. (1)

3. The arm-mounted pen-holder snags cables and equipment when observers change station. (1)

[redacted]

General Summary

This station is noisy, but only just above average for the aircraft. The main environmental stress derives from inadequate ventilation of the compartment when it is curtained off. A comfortable seating position is difficult to achieve because of insufficient clearance beneath the table (see Figure 7), and the need to sit back in order to obtain an adequate work-surface for charts, etc. Layout of displays and controls is grossly inadequate. Figure 7 illustrates that this results from the need to space out separate items of bulky equipment, each containing a scattering of controls. Little or no attempt has been made to position controls within the normal reach of a seated operator, nor to orient displays correctly to his line of sight. The right-hand scope was considered to be virtually useless.

Recommendations

Short-term improvements in comfort and efficiency are difficult to recommend, because of the component nature of the equipment. Replacement of the two scopes by one having a larger display face and less bulky associated control equipment would be advantageous. Any equipment remaining on the upper rack should be brought forward and angled downwards within easy reach. All controls should be placed above the work-surface, near their associated displays, and grouped by function. A number of separate controls could be ganged, to reduce manual load, and obsolete controls should be removed to prevent confusion. It seems essential to provide this station with some form of independent ventilation, to reduce discomfort when it is curtained off.

Long-term improvements should aim at designing this position as an integrated console, instead of a collection of isolated components. Ample information on the design of consoles of this type is provided in Chap. 4 of the U.K. Medical Research Council handbook (1971) and general design information is obtainable from Morgan, et al, (1963). A more efficient method of transmitting tactical information from this station to the Tactical Navigator should form part of any major modification.

E.C.M. Operators

Displays

1. The APA74 analysis scope plus the KD2 camera is so badly positioned that the operators virtually have to leave their seats in order to read it. (6)
2. The APA69A scope is difficult to read, because of its position above eye-level. (5)
3. The IP81 frequency counters are difficult to read. Coarse graduations and poor illumination lead to errors. (2)
4. The compass rose is oriented differently from that at the Radar Operator's station (aircraft heading at the top of the scope, instead of North). This is confusing when rotating among stations. (1)
5. The displays are considered to be outdated and the operators' confidence in detection is low. (2)

Controls

1. Controls are generally too scattered and cannot be seen or reached easily from the normal viewing position. Labelling is almost illegible in some cases. (4)
2. Some controls (e.g., OFF/PAN, OFF/NAT) are now non-functional, but still occupy valuable space. (4)

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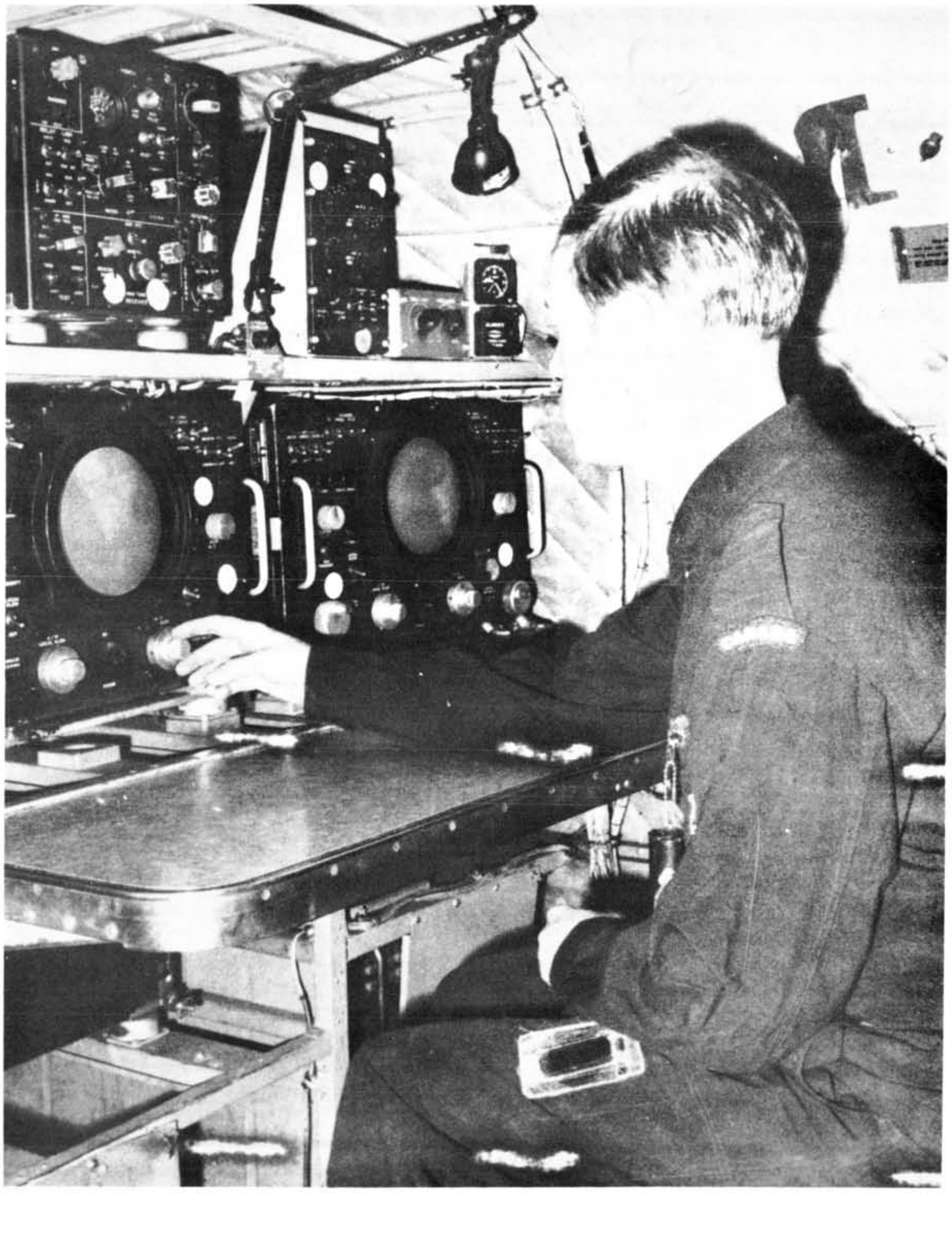

Figure 7. Inadequate table-space and leg-room impose a tiring posture on the radar operator.

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3. Panel and table light switches are located just above the antennae controls and are of similar type and shape, increasing the probability of accidental operation. (4)

4. The antennae switching controls are too fussy. The OFF/INCH/NORMAL switching is not standardised among all aircraft. (2)

5. Ancillary controls are scattered all over the aircraft. (1)

Workspace

1. The seat is uncomfortable, difficult to adjust to a suitable viewing position and there is inadequate leg room. (2)
2. Table space is inadequate for the charts etc. which have to be used at this station. (1)
3. The station faces sideways, so that the main displays are 90° out of phase with aircraft heading. Operators take a while to reorient themselves when changing position. The display datum for aircraft heading is less than helpful, because it differs from that at the Radar Operator's station. (1)

Environment

1. Noise and vibration levels are too high. (5)

2. Heat distribution is uneven. (5)

Personal Equipment

1. The helmet is useful for preventing head injuries from the badly positioned APA74 and KD2 camera, but the gross head and body movements required at this station make the helmet uncomfortable to wear for prolonged periods. (3)

General Summary

The outstandingly bad feature of this station is the positioning of the main displays. Even with the seat adjusted to its highest position, there is a 33-inch difference in height between the depressed seat cushion and the centre of the APA 69A. Data presented by Woodson and Conover (1966, Table 5–17) indicate that 95% of the male population would need to look *up* at this display, a fatiguing posture to maintain for long periods, especially when wearing the Gentex helmet. Figure 8 illustrates the point and also shows the awkward positioning of the KD2 camera. Figure 9 emphasises both points, but illustrates, in particular, the extremely tiring posture it is necessary to assume when checking the APA74 analysis scope. Controls are badly positioned for reliable operation during visual monitoring of the displays and the probability of accidentally operating the wrong control seems high. Little confidence was expressed in the detection capability of the equipment, because of its narrow bandwidth. Workspace is limited. Some operators experience difficulty in orienting themselves with respect to the display datum, rather than to aircraft heading, in this sideways-facing position. The combination of a side-facing position with a task which requires gross head and eye movements is also conducive to motion sickness (see Section V). The high levels of noise and vibration, and the large vertical temperature gradient, cause discomfort here (as at most other stations).

Recommendations

Short-term improvements in comfort and operational efficiency should aim at lowering the displays without radically changing their viewing angle of about 90° to the line sight. Consideration might be given to stacking the APA74 above the APA 69A at one position with both display surfaces aligned

[redacted]

vertically and in side elevation, and the upper display centred no higher than 33 inches above the level of a maximally extended seat. This modification would require relocation of controls on either side of the displays. It may also require the displays and controls of the other position to be comparably laid out, to prevent confusion. Attention should be given to shape-coding the presently identical control knobs, to facilitate selection while the operator is viewing the display. Obsolete equipment should be removed from the station.

Long-term improvements would necessitate a complete redesign of the seat, workspace and console layout, as specified for the Navigator's stations. Consideration might be given to a forward-facing orientation, to align the displays with aircraft heading and reduce the incidence of motion sickness.

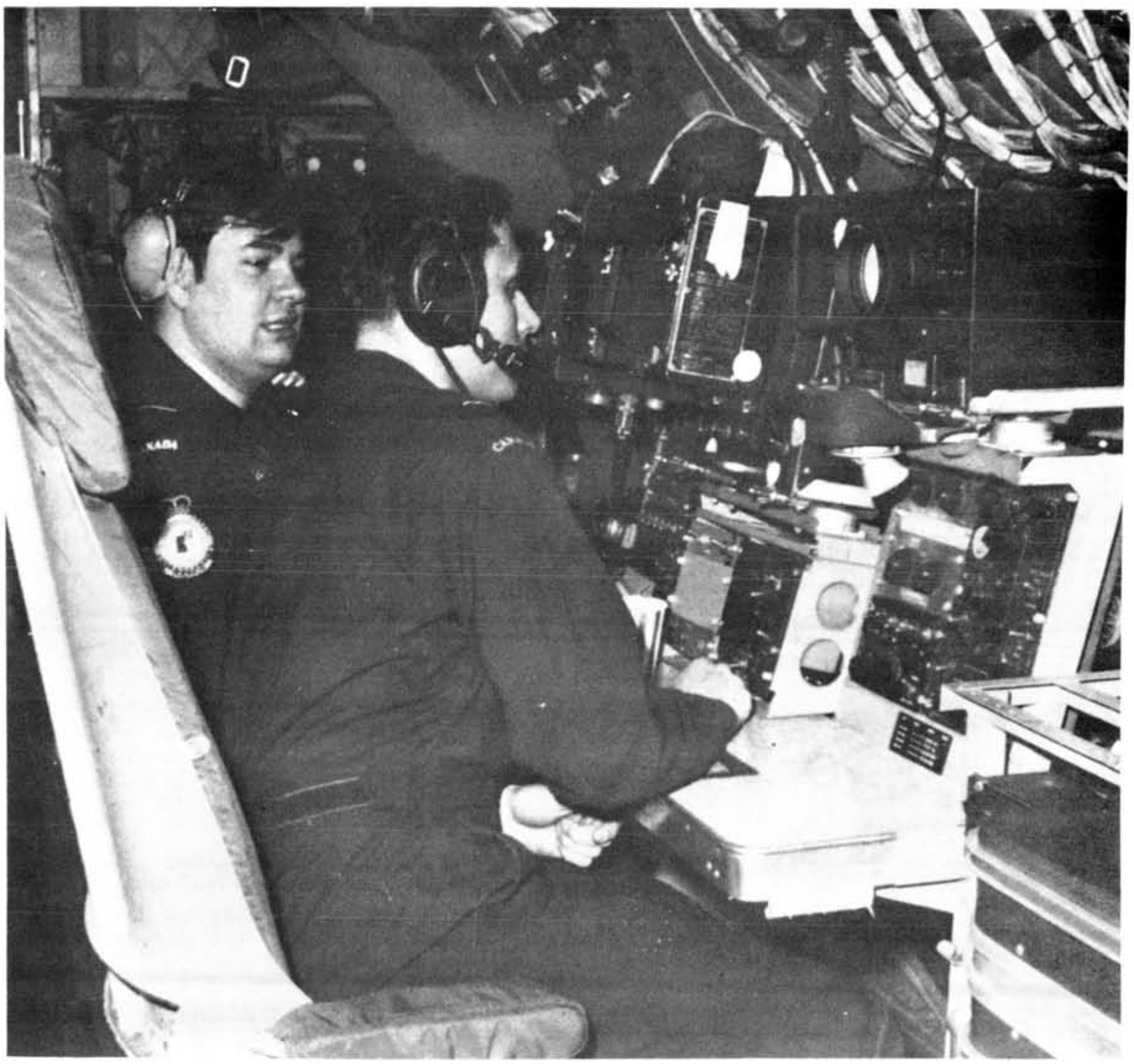

Figure 8. The main displays of the ECM operators are too high for comfortable monitoring over long periods.

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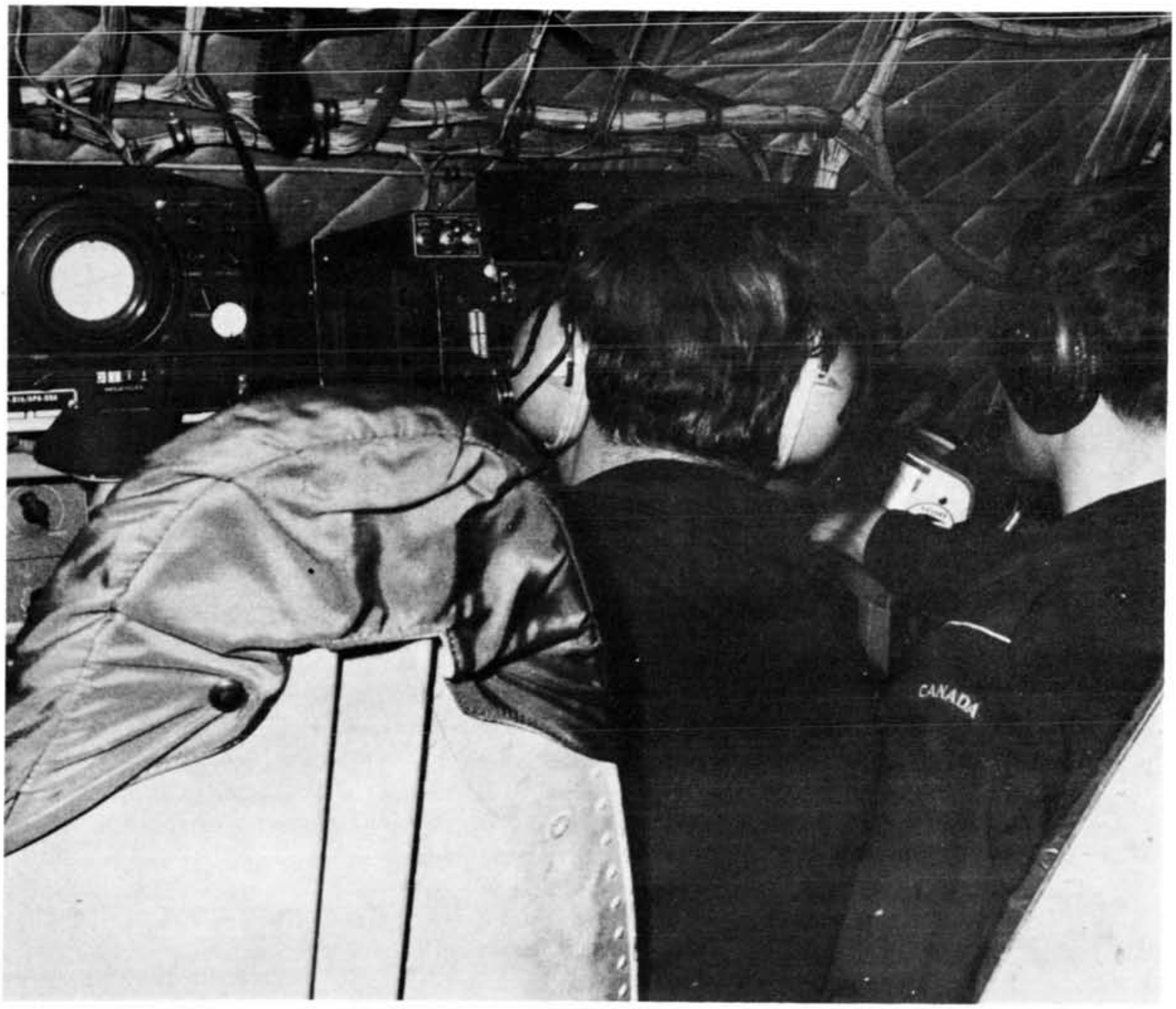

Figure 9. The awkward positioning of the APA 74 analysis scope forces the ECM operators to adopt extremely tiring postures.

MAD/Julie Operators

Displays

1. The pen recorders are too high and angled too vertically. (3)
2. Display lighting is generally poor and a source of glare. (2)
3. MAD equipment is oriented badly in relation to the operator's line of sight. (2)
4. The MAD operator needs a 'turn and bank' indicator, an altimeter and a compass, for information on aircraft position. (2)
5. Better headphones are needed for aural detection. (1)
6. Meters on the tape-decks are difficult to read when carrying out checks. (1)
7. A better visual display is needed for active sonobuoys and explosive echo ranging. (1)

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Controls

1. The tape-deck controls are too distant and selections have to be made for the Jezebel Operator, who is completely out of reach of these controls. (2)
2. The sonobuoy receiver controls are not readily accessible. (1)
3. There is not complete consistency in control positioning for the two recorders, causing confusion. (1)
4. The method of relaying information to the Tactical Navigator is inadequate. (2)
5. Intercommunication cords are confusable and become tangled. (1)

Workspace

1. Seats are uncomfortable and provide insufficient restraint during MAD and Julie manoeuvres. (2)
2. The two positions are too crowded; one man can physically impede the other. (1)
3. Table space is insufficient. (2)

Environment

1. The noise level is too high for effective aural detection and it also interferes with intercommunications. (2)

Personal Equipment

1. The helmet is uncomfortable, especially on MAD manoeuvres when the operator attends to the top of the display. (3)

General Summary

This is one of the better stations, from a human factors point of view. The displays are relatively clear, the main controls are not too inaccessible and there seem to be few problems of incompatibility between display and control movements. However, the recorder displays are not ideally positioned for a comfortably seated operator and controls on the overhead panel are far too distant. Both these deficiences are illustrated clearly in Figure 10, which also shows the difficulty of positioning the lamp so that it adequately illuminates the work-surfaces without obstructing vision. The major difficulties at this station are the crowded workspace, uncomfortable seating and high noise levels, which are said to degrade detection performance and intercommunication.

Recommendations

Short-term improvements could be gained by moving the tape-decks to a position nearer the Jezebel Operator, shifting the MAD/Julie station into the space so gained, repositioning the displays at a more convenient height and angle of view, and lowering the overhead control panel to within easy reach. The layout for both recorders should be standardized and colour-coded. Reel-in intercommunication cords should be employed.

Long-term improvements in efficiency will be severely restricted, unless the audio signal-to-noise ratio can be improved (see Section IV). Given this improvement, work-space redesign could proceed as outlined for the Navigators' stations.

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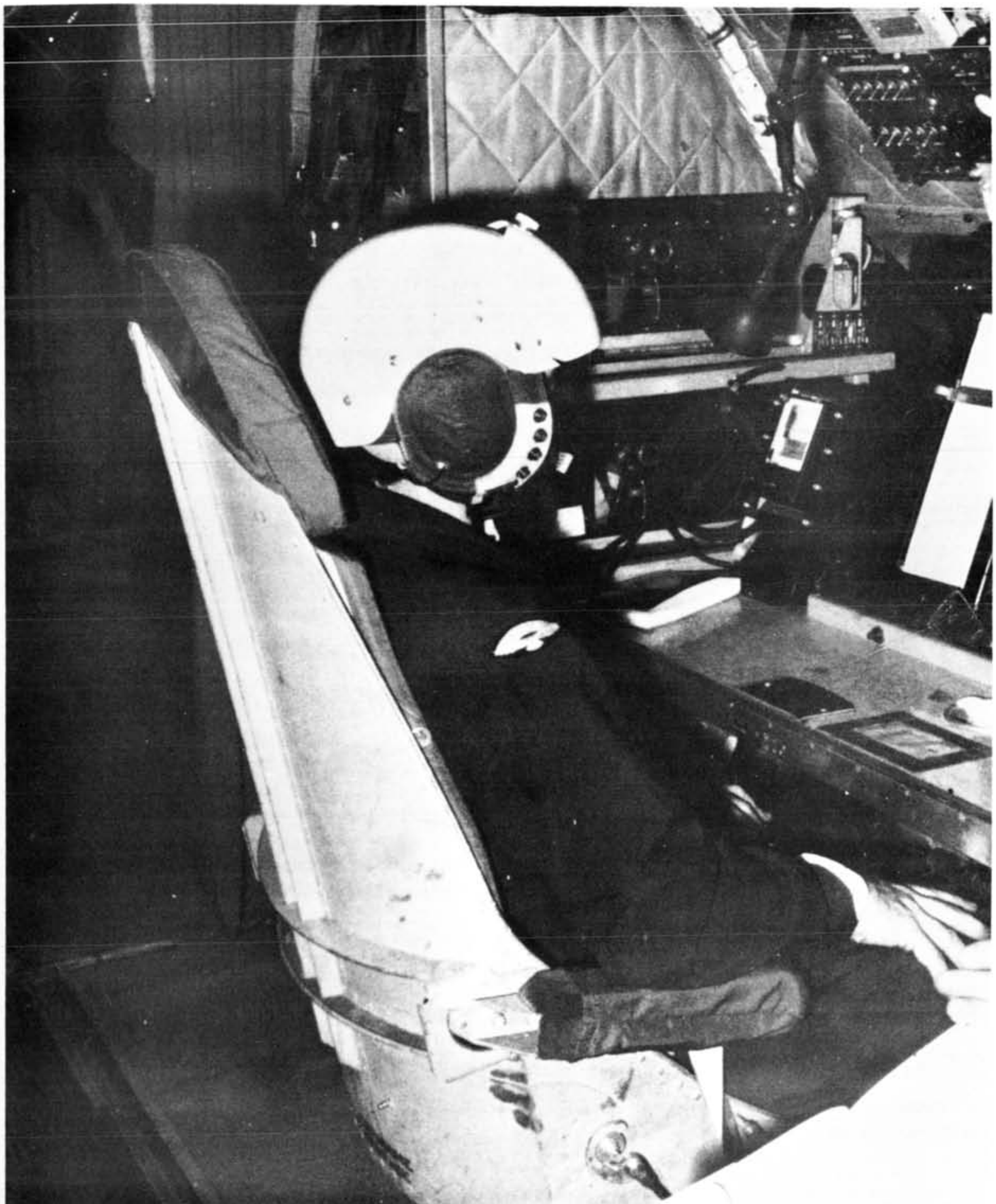

Figure 10. The main display and overhead controls are too distant for a comfortably seated MAD/Julie operator.

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ASW Stores Launcher Area

Displays

1. Sonobuoy numbers are difficult to read at night, especially those in the forward rack. (1)

Controls

1. The launchers are old and unreliable. (2)
2. The librascope which dispenses charges is also unreliable and has sharp corners which are a potential source of injury. (1)
3. Sonobuoys are difficult to load in the present type of launcher. (1)
4. Stores require both hands for loading. Therefore manual operation of the intercommunication switch is difficult. (1)
5. The retro which fires smoke markers often jams. (1)
6. The long-burning marker has extremely sharp corners, which have been known to cut through gloves during handling. (1)

Workspace

1. Carrying stores through the limited workspace during manoeuvres is hazardous. (1)
2. The height of the sonobuoy launchers hampers movement. (2)
3. The urinal should not be sited in this workspace. (1)

Environment

1. The aircraft motion is troublesome during manoeuvres. (3)
2. The compartment is noisy when the chutes are open, making intercommunication difficult. (2)

General Summary

There are three distinct problem areas in this compartment. Firstly, carrying stores a distance of some 15/ft and down a step through a crowded workspace, during the imposition of high acceleration forces, is a difficult exercise, which inhibits good intercommunication (because of the requirement for manual switching) and which is liable to induce motion sickness. Secondly, the launching equipment is worn and unreliable. Thirdly, there is a noise problem for good intercommunication during critical manoeuvres, when the crew member launching stores has his head near an open chute.

Recommendations

Short-term improvements could be effected by clustering stores nearer to the launch area, preferably stacked horizontally in racks on either side of the launchers. Some method of resting stores above the launchers and guiding them into the chutes preparatory to launching, would ease the present manual load. Knee- or thigh-operated intercommunication switches on the safety rail around the launchers would solve the difficulty of intercommunicating during two-handed manipulation of stores. More legible labelling of sonobuoys, and/or higher levels of illumination within the area, would improve discriminability of stores.

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Long-term improvements might include the design of a stores area which could be set out within reach of a standing man wearing a suitable restraint harness. A more sophisticated system providing remote handling of stores from the Tactical Navigator's station might also be considered.

Nose and Beam Search Stations

Displays

1. Plexiglass in the nose and beam stations is scratched and distorted. (In addition, the view through the nose bubble is sometimes obscured by static discharge bands). (6)
2. The wiped area of the nose bubble is too small and too low. (1)
3. There is insufficient depth to the bubble at the port and starboard stations. (1)
4. Illumination is bad at night in the nose. The compass rose should be self-illuminated, as should the intercommunication control box. (1)
5. Julie operation would be easier if the Nose Observer had a display of the 'sono-homer' channel selected by the Pilot. (1)

Controls

1. Operating the heavy, hand-held cameras from beam stations is difficult and aiming is done largely by guesswork. (1)
2. Lighting controls in the nose are too far back and labelled illegibly. (1)

Workspace

1. Seats in the nose and beam are uncomfortable. (3)
2. Entry to the nose is extremely cramped.
3. The nose seating position is so far back that sideways vision is restricted. (1)
4. The sill of the port and starboard stations catches the knees. (1)

Environment

1. Temperature inside the nose bubble varies too widely with outside temperature. (4)
2. The windscreen-heater fan-unit and the ASR 3 unit in the nose are too noisy. (1)
3. There are leaks in the nose bubble which shower the observer with water. (2)
4. The port lookout station is draughty. (1)

Personal Equipment

1. The helmet causes extreme discomfort when leaning forward in these stations for prolonged periods. (2)
2. Zips on the knees of the flight suits are uncomfortable when crawling into the nose. (1)

[redacted]

General Summary

The major problem at these stations is the limitation on visibility caused by smearing and defects in the plexiglass. The use of hand-held cameras at the beam search stations is of limited effectiveness, because of the weight and length of the camera and the shallow depth of the plexiglass bubble. Seats are poorly designed for the task, which requires the observer to spend long periods leaning forward. There is insufficient footspace between the chair-rail and the hull of the aircraft, forcing the observer to adopt an unstable, tiring posture as shown in Figure 11. The helmet is also tiring in this head-down position.

Recommendations

Short-term improvements could be gained by regular cleaning of the bubbles and a policy of replacing scatched and distorted plexiglass. The few displays and controls at the nose lookout station should be illuminated, moved forward and relabelled. The seat in the nose should be moved forward and the upper part of the plexiglass tinted to reduce solar overheating. Noise sources should be moved outside the nose compartment.

Long-term improvements could, in addition, be gained by the use of low light level TV to improve observation and recording in poor visibility. Consideration should be given to the design of a special seat for these lookout stations, since observers generally adopt a semi-supine posture for which the present seat provides inadequate support.

CONCLUSIONS

The Argus is an ageing aircraft and it is therefore hardly surprising that the design of its crewstations fails to meet human factors standards of the 1970's. It is clear that most workspaces have been assembled on an engineering concept. In other words, they comprise a selection of component equipments fitted around a standardised operator's seating position, wherever space is available. Within each equipment, components are assembled largely on space-saving criteria and with the objective of minimizing the length of wiring and pipe-runs. This has generally resulted in the man being confronted with individual items of bulky equipment, containing displays which cannot be readily scanned and controls which are scattered beyond easy reach. Consequently, the visual and manual load on the crew is unduly high.

Using the alternative human engineering concept of workspace design, the man's operational functions are first clearly defined, displays are then selected to provide the information he requires (in the form he requires it), and controls are chosen for ease of discrimination and manipulation of the displayed variables. A suitably sized console is then designed around a comfortable seating position, so that all displays can be rapidly scanned and all controls fall within easy reach. Displays and controls are grouped together according to their association within operational sequences, rather than according to their engineering function and eye and hand movements are thus minimized. A number of other techniques are available to obtain the most efficient match between operational requirements and human performance characteristics (e.g.: Chap. 4 of U.K. Medical Research Council Handbook, 1971; Damon et al, 1966)

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Figure 11. There is inadequate foot-space for the beam observers.

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APPENDIX B

AGE AND FLYING EXPERIENCE OF THE CREW

CREW	AGE	FLYING EXPERIENCE	
		HRS. IN ARGUS	HRS. IN OTHER AIRCRAFT
Pilot	37	1700	8325
"	37	1500	5200
"	26	2000	1450
Navigator	39	1200	4200
"	30	3100	300
"	38	1200	8100
"	23	500	200
Observer	25	1690	110
"	26	1000	900
"	35	1200	40
"	27	1400	50
"	29	400	0
"	39	2500	2000
Flight Engineer	38	3400	788
" "	39	800	8690

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APPENDIX A

FLIGHT SCHEDULE

Flight # and date	From	Take-off (Zulu)	Route	To	Touch-down (Zulu)	Total flying time (hrs.)	Total distance (nautical mls.)
1. Jan. 25, 1972	Greenwood	04.00	Seven Islands, Menikek, Hall Beach, Uranium City.	Namao	19.24	15.4	2810
2. Jan. 27-28, 1972	Namao	13.00	Fort Simpson, Mackenzie River, Inuvik, Richard Island, Cape Young, Uranium City	Namao	05.48	16.8	2803
3. Jan. 29-30, 1972	Namao	10.00	Belcher Islands, Pistolet Bay, Strait of Belle Isle, Gulf of St. Lawrence	Greenwood	03.06	17.1	2682
					Total time and distance	49.3	8295

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APPENDICES

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Heat distribution should be improved, to reduce the present vertical temperature gradient which may be as high as 50 degrees(F) in places. Humidity should also be increased to reduce the frequency of upper respiratory infections.

The capability of the galley facilities should be improved, in order to cater adequately for the number of crew normally carried on routinely prolonged flights.

Any redesign of crewstations should aim at a reduction in the size and frequency of head movements required to scan the displays, especially within the tactical compartment, where the present side-facing seating arrangements are conducive to the production of nausea, vomiting and fatigue symptoms.

Attention should be given to the possible redesign of flight-scheduling, so that adequate sleep can be taken before a flight and so that there is minimal disruption of the crews' normal circadian rhythms of physiological activity.

Servicability of the aircraft should be improved, to reduce take-off delays and cancellations and thus maintain crew morale at its present high level.

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backrest, extending the range of height adjustment, relocating seat runners (especially at the Beam Search Stations) to provide adequate foot- and knee-room, and introducing thicker all-round padding. Even these improvements would not fully meet the demands of the search stations, where consideration might be given to the design of a semi-supine position, to match the posture required by the task.

Only the Pilots and Flight Engineer have workstations which reflect a reasonably acceptable level of human engineering. Even here, there is considerable scope for improvement by relocating a number of ungrouped displays and controls and ensuring that all important displays lie within the normally scanned area. The remaining flightcrew and tactical stations have human engineering problems of varying severity. The Routine and Tactical Navigators' stations are outstandingly bad. The Radar, Radio and ECM Operators have less severe interface problems, but their stations fall well below modern standards of human engineering design, as does the ASW Stores Launcher Area. The Jezebel, MAD and Julie Operators have relatively minor interface problems, although here again there is considerable scope for improvement.

Recommendations for interface improvements fall into two widely disparate categories. Immediate attention could be given to the following short-term improvements:

(a) Remove all redundant displays and controls.

(b) Relocate those displays which fall outside the normally scanned area, or which cannot easily be read when the operator is manipulating its associated control.

(c) Relocate those controls which are beyond easy reach, or which are normally out of sight of the seated operator.

(d) Standardize the layout of displays and controls for all aircraft of this type.

(e) Provide a lighting system which does not obscure the displays and controls.

There will be a low upper limit to any increase in comfort or operational efficiency gained by these improvements, because of the overriding engineering design concept of the crewstations. Most operators will still be faced with a variety of scattered, bulky equipment which cannot be acceptably laid out around the seating position.

It follows that additional gains in comfort and efficiency could be obtained only by a complete redesign of all crewstations using human engineering criteria. This could be achieved in two ways:

1. By breaking down the separate component equipments at each crewstation and relocating displays and controls around the workspace according to their use in the operational sequences at that station.

2. By replacing the present components entirely with updated equipment which has itself been designed on human engineering criteria.

The former alternative has the limitation that it would retain many outdated displays and controls which are far from ideal interface components. The latter alternative has the limitation that it retains the aircraft with its high and virtually irremediable levels of noise and vibration.

One cannot escape the conclusion that a redesign exercise using human engineering criteria would be most cost-effective if it started with an aircraft having lower noise and vibration levels.

HABITABILITY AND CREW FATIGUE

There is tremendous scope for improving the habitability of the aircraft. The most urgent requirement is for a commercial aircraft-type lavatory to replace the existing hazardous arrangements for human waste disposal. Another prime requirement is for improved rest-space facilities and elimination of the need to sleep on make-shift beds in the ASW Stores Launcher Area.

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CONCLUSIONS AND RECOMMENDATIONS

NOISE AND VIBRATION

The outstanding feature of the aircraft is its high noise level. At high engine speeds (2320 rpm) the overall sound pressure levels range from 113 dB in areas close to the plane of propeller rotation, to 104-109 dB in the Tactical Compartment and ASW Stores Launcher Area. The noise is predominantly low frequency and cannot be reduced by practicable sound-treatment procedures. However, the risk of hearing impairment is minimal for crew members who wear effective hearing protection and routinely work away from areas of maximum noise.

The Radio Operator is located in the worst possible area of the aircraft. Noise masking is such that the receiver amplifier gain has to be set to a fairly high level in order to hear incoming signals. The resulting receiver noise, combined with aircraft noise, produces noise levels under the flight-helmet earphones which are potentially hazardous to hearing, in the long term.

Ideally, the Radio Operator should be relocated in a less noisy area of the aircraft. However, it would be possible to reduce the noise hazard immediately by wearing properly fitted ear plugs under the helmet. In addition, this would probably produce an increase in speech intelligibility by reducing speech and noise levels below the overload region of the auditory system.

Moderately high levels of vibration occur in structures (such as desks and tables) in close proximity to the aircraft engines. The application of suitable isolators to these structures should reduce the effects of secondary vibration exposure on the crew and control the re-radiation of noise within the aircraft.

Voice communications within the aircraft, using the AIC/10 system, are not seriously hampered by noise when engine speed is less than about 2200 rpm. At speeds greater than this (e.g., during takeoff or tactical operations) communication efficiency may be reduced.

MASKING OF SONAR SIGNALS

The intense low-frequency energy coming from the engines of the Argus will mask most active sonar returns that are less than 70 dB SPL and many that are as much as 80 dB SPL. It would be very difficult to reduce the low-frequency energy reaching the observer's ears, short of replacing the aircraft's engines with jet engines. It would be possible to lower the threshold for detection by about 20 dB (a substantial reduction) by increasing the display frequency for the sonar returns to 1850 Hz from the 850 Hz that is presently used.

In addition, the aircraft engine noise adversely affects auditory processing of transient passive sonar information, since it almost completely masks sound in the frequency region below 500 Hz, where most ship and submarine sounds occur. But this is not so serious as the active sonar detection problem, since the passive sonar task is primarily visual.

HUMAN ENGINEERING OF CREWSTATIONS

Throughout the aircraft there is a seating problem. Only the Pilots are able to make substantial use of the backrest and, even here, there is a mismatch between head-rest design and the requirement to wear flight helmets. However, seating comfort for the Pilots could be optimised, for the existing seat, by introducing an adjustable head-rest and increasing forward adjustment of seat position by about two inches. At all other crewstations, seating comfort could be improved only by providing an adjustable

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rest are difficult to obtain, because of high noise levels in the rest areas or the discomfort caused by sleeping in a headset or flight helmet. More than half the aircraft and operational features which earlier studies have identified as causal factors in the production of fatigue, co-exist in the use of Argus aircraft on Northern Patrols. The high level of unservicability of the Argus is a potential depressant of morale among air and ground crews.

It is clear that these factors will often combine to produce an overall lowered level of operational efficiency. Many of the factors are particularly conducive towards the impairment of detection performance and of tasks requiring critical decision-making.

SHORT-TERM RECOMMENDATIONS TO REDUCE FATIGUE AND IMPROVE CREW EFFECTIVENESS

1. (a) Require wearing of flight helmets only for take-off, landing, action stations, and during periods of turbulence.

   (b) At other times permit the wearing of light weight headsets with good sound-attenuating qualities, or effective hearing protection (see Section III).

2. (a) Provide more rest facilities away from disturbances such as those emanating from the galley and lavatory.

   (b) Provide odour-free and turbulence-resisting facilities for elimination of human wastes, with sufficient capacity for the maximum number of air- and ground-crew carried, and of a standard comparable with that of Canadian Forces passenger aircraft.

   (c) Provide more uniform heat distribution vertically and horizontally throughout the aircraft.

These recommendations are additional to the suggested human engineering modifications to displays, controls and workspaces, listed in Section II, the suggestions for minimizing noise problems, listed in Section III, and the suggestions for improving detection performance, listed in Section IV, all of which would be expected to reduce fatigue, in addition to improving crew effectiveness.

LONG-TERM RECOMMENDATIONS

1. Turbo-jet or jet engines which generate far less low-frequency noise, should be considered as alternatives to the present engines.

2. Ten- or 12-hour duty cycles should be considered. This duration is around the maximum time for continued operational performance without undue fatigue.

3. Ideally, flight scheduling should take account of circadian variations in physiological activity, so that disruption of sleep is avoided and watch-keeping and decision-making tasks are not required at those periods in the 24 hours when the crew would otherwise be sleeping.

These recommendations are also additional to the long-term improvements suggested in Section II.

circadian rhythms and the operational demands on aircrew. For example: it may be daytime on arrival at a destination, but 'physiological night-time' for the crew, who would normally be sleeping then, and vice versa. The flight schedules necessitated by Northern Patrols will thus inevitably disrupt normal sleep-patterns and will force aircrew to operate through periods when, physiologically, they are ill-equipped to maintain alertness and efficiency.

Pre-flight and in-flight delays will obviously exaggerate the problems of fatigue which result from long work-periods. The present state of unserviceability of the Argus aircraft (see Appendix N) must therefore be considered as a contributory factor in fatigue incurred on both Maritime and Northern Patrols, apart from its potentially adverse effect on crew morale.

It should be noted that fatigue of the degree experienced by Argus crews will seldom cause a complete breakdown in performance. It will, however, produce an increasing demand for extra effort in order to maintain performance. A complicating factor is that operators will not always be aware of their deteriorating performance standards, since the onset of fatigue is insidious. Its adverse effect on self-judgment is comparable with that of alcohol intoxication or hypoxia. Operational performance will therefore be degraded in ways which are difficult to detect and correct. An example of this effort was observed during the third flight, when an observer was seen to stare fixedly out of the Beam Search window for long periods, instead of using his regular scanning procedure.

It is remarkable that more overt manifestations of fatigue were not observed, considering that, from January 25 to 29, the crew flew 49.3 hours in a noisy, vibrating aircraft with unsatisfactory heating, substandard sanitary conveniences and inadequate rest facilities, while undergoing frequent disruptions of their circadian rhythms. It seems highly probable that good morale, physical fitness, thorough training, crew spirit, strong leadership and a sense of accomplishment deriving from a belief in the intrinsic value of a mission, are all pertinent factors which delay the behavioural manifestations of fatigue. In addition, the ability to move around the aircraft as tasks rotate among crew-members must also offset the adverse psychological and physiological effects of fatigue.

CREW MORALE: FUTURE CONSIDERATIONS

Although morale seems high at the moment, there is no certainty that this state will continue as the incidence of failure in the major systems of the Argus becomes significant (see Appendix N). Unless this situation can be controlled it may be construed as evidence of a downgrading of the aircraft's role, which would almost certainly depress the morale of both air and ground crews, with consequent effects on performance.

CONCLUSIONS

Argus crews on Maritime and Northern Patrols are subjected to a number of potentially avoidable stresses which predispose them to excessive fatigue and impaired performance. The long hours and flights across time zones, plus the delays caused by aircraft unservicability, produce a working schedule which disrupts normal sleeping habits and forces the crew to operate at certain times in the 24-hour period when they are sub-optimally efficient for physiological reasons. The low atmospheric humidity and the variable, and often low, temperatures obtaining within the aircraft cause discomfort and are potential sources of performance impairment, largely because of their distracting effects. Sanitary arrangements are primitive in the extreme and provide a highly potential source of infection, when coupled with the poor and inadequate washing facilities. The galley is inadequate, especially when ground crew are carried. Sleep and

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Aircrew Fatigue

It is relevant at this juncture to consider the factors observed to contribute to fatigue in previous studies, for example that conducted by the RCAF during the Tokyo Airlift (McGrath et al, 1954). The main overt expressions of fatigue were irritability, sleepiness, lowered standards of performance and delayed reaction time. Major causal factors were said to be as follows:

a. Factors common to flying in general:

(1) Length of flight*;
(2) Delayed flight*;
(3) Details prior to takeoff*;
(4) Monotony and boredom on familiar routes*;
(5) Number of intermediate stops;
(6) Drinking the night before.

b. Factors relating specifically to operational conditions:

(1) Problems relating to particular aircraft:
(a) High level of noise and vibration*;
(b) Unreliable and inadequate heating systems*;
(c) Cramped working conditions*;
(d) Poor arrangement of instruments*;
(e) Uncomfortable oxygen masks.

(2) Problems relating to particular routes:
(a) Food;
(b) Quarters;
(c) Transportation;
(d) Working Hours*.

c. Personal Factors:

(1) Inexperience;
(2) Tension among crews;
(3) Responsibility*;
(4) Domestic worries*;
(5) Personality*.

If one substitutes heavy and uncomfortable helmets for the oxygen masks listed in b, (1) (e) above, more than half of these factors must be considered to provide permanent sources of fatigue in the Argus aircraft flying Northern Patrols.

The earlier classic research in this area, much of which was reviewed by Bartley and Chute (1947), confirms the potentially fatiguing effect of these factors and there is additional confirmation from other field studies, such as that by Standbridge (1951) of the Berlin Airlift. More recent studies have tended to emphasise the importance of rhythmic daily changes in the body's physiological activity (circadian rhythms) as a factor in efficiency of performance (Anon, 1962, 1971b; Blake, 1969; Frazier, 1968; Klein et al, 1970, 1972; Nicholson, 1970, 1972; Webb and Agnew, 1971; Wilkinson, 1969). Performance is generally found to be more efficient at the higher levels of physiological activity normally occuring in the late afternoon among people working during daylight hours. Performance is maximally inefficient for these people if they are required to work during the early hours of the morning, when they would normally be sleeping. Flying across time-zones will obviously impose an out-of-phase relationship between these

*Factors specifically inherent in the Northern Patrol task of Argus crews.

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Figure 18. Additional ground crew attempt to relax in the beam search station seats.

Opportunities for taking rest before the first flight from Greenwood to Namao were not good, since with a takeoff at midnight (local time), crew members obtained rest at home, with all the problems implicit in resting while active children are awake. In addition, most crew members had duties related to the flight which required their presence on Base at varying times, and for varying durations, throughout the day prior to flight. The crew commander and lead navigator normally have a minimum of three hours of work to perform prior to the preflight briefing. By the time preflight preparations and briefings are accomplished, and the aircraft is loaded and secured for takeoff, most crew members have been on duty for a considerable time and key flight personnel have already worked up to seven hours before initiating a flight that may be of 15 or 16 hours duration. Time out of bed at the conclusion of the first mission thus ranged from 19.4 to 22.4 hours. Rest facilities at CFB Edmonton (Namao) between the first and second, and between the second and third flights, were excellent.

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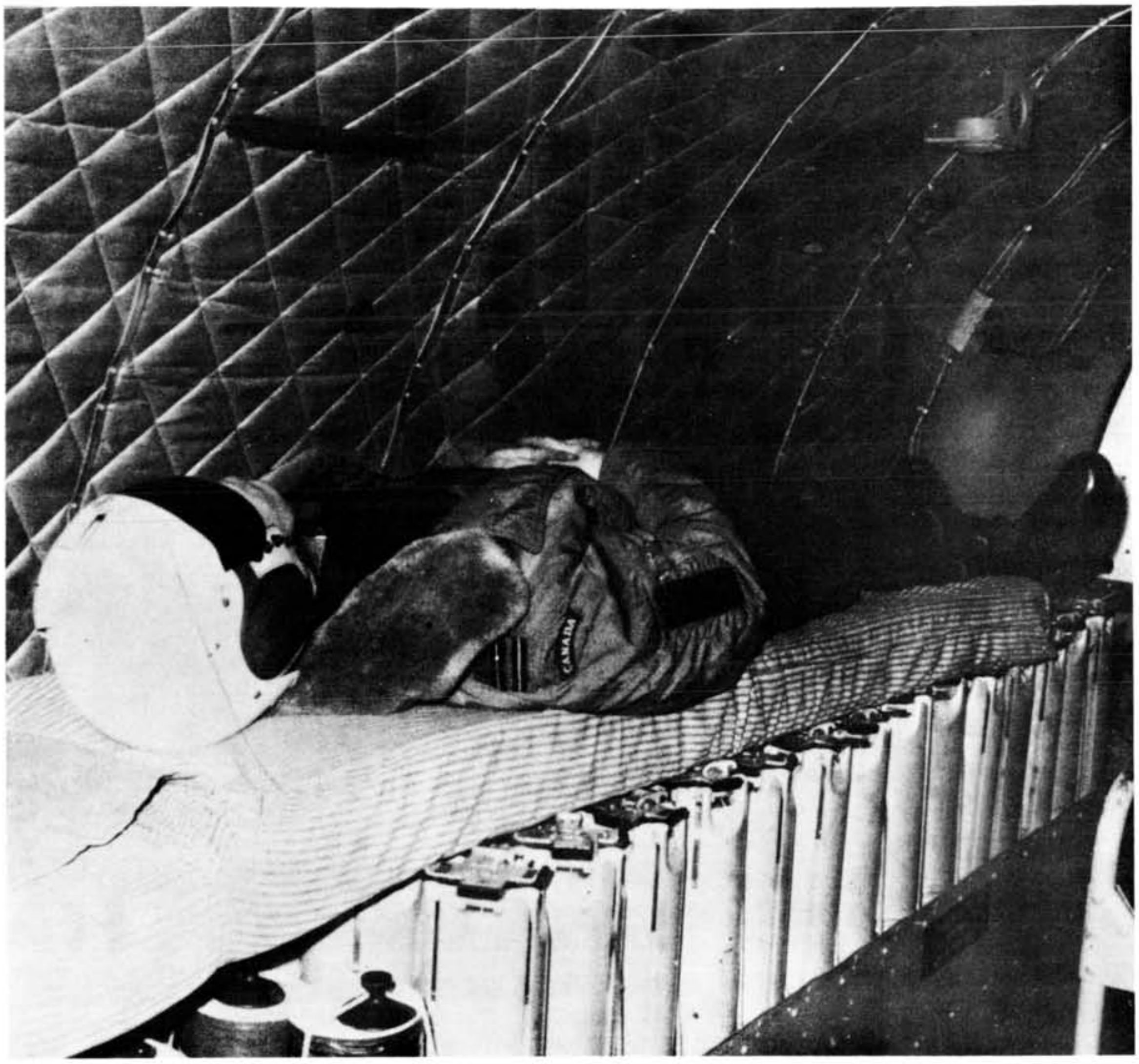

Figure 17. Additional sleeping facilities are provided by throwing spare mattresses over the aft sonobuoy storage.

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Clinical Illness and Physiological Disturbance

During the three flights there were five cases of upper respiratory infection (common colds), two cases of gastroenteritis with acute diarrhea, one barotrauma of the left ear, with blood in the middle ear and severe pain, one episode of disorientation in monochromatic whiteout conditions, and one case of air sickness with vomiting. Two crew members exhibited significant auditory fatigue (temporary threshold shifts in excess of the CHABA limits, see Section III).

The instrument layout at some crewstations in the tactical compartment of the aircraft is a major cause of the relatively high incidence of motion sickness previously reported among Argus crews (Reference 32). The aft ECM Operator is particularly vulnerable to motion sickness, especially at the time he can least afford to be incapacitated, that is, when a cloverleaf search pattern is flown. While sitting at right angles to the longitudinal axis of the aircraft, without outside visual reference and while subjected to changing angular acceleration as the cloverleaf pattern is flown, the ECM Operator must vary his head movements between straight up and down, and back and up to the left. Such movement causes frequent disturbances of fluid flow in the semi-circular canals of the inner ear and stimulation of the otoliths (Money, 1970) which tends to create nausea, vomiting and fatigue even in the hardiest person. This Coriolis phenomenon could be minimized by arranging visual displays in such a way that large head and eye movements are reduced or eliminated; that is, key visual displays should be in the line of sight of the operator (as suggested in Section II). Headrests which would allow the operator to anchor his head during changing angular accelerations and still effectively accomplish his task would also help reduce motion sickness.

Although the aft ECM Operator represents the worst case of design-induced Coriolis phenomena and motion sickness, this observation applies in varying degrees to all tactical compartment crew members. A general reduction in motion sickness and fatigue, and overall improved crew effectiveness would therefore be expected to result from measures designed to reduce head movements.

Cooking odours from the galley and odours from the faeces bucket which is immediately adjacent to the tactical area further increase susceptibility to motion sickness.

Rest Facilities

The major provision for sleeping is a rest area containing four bunks, provided only with bare mattresses and situated in an area where noise levels are of the order of 105 dB and temperatures remain in the upper 70s. Their close proximity to the galley and toilet are also disturbing. When additional sleeping facilities are required, crew members use spare mattresses thrown over the aft sonobuoy storage (see Figure 17) or attempt to relax in the beam search station seats (see Figure 18). Noise levels at these locations are comparable with those in the main rest area (see Appendix C). However, temperatures are considerably lower over the sonobuoy storage (around 60°F, see Appendix M), and extremely variable at the Beam Search Stations (a vertical gradient of about 50 degrees). Some people have difficulty sleeping anywhere within the main or subsidiary rest areas, because a flight helmet or headset is uncomfortable to wear while sleeping, yet the noise levels preclude sleep if the device is removed. It must be pointed out, however, that most people can sleep with well-fitted ear-plugs, which provide similar noise attenuation to the helmet or headset.

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minute. Between the flight deck and the galley, floor temperatures varied from 24°F to 33°F. Waist-level temperatures in this forward section of the aircraft were around 36°F. After fifteen minutes of backup heating, waist-level temperatures in this forward section were 53°F. Aft of the galley they had reached 68°F.

It may be concluded that the backup heating system would maintain temperatures at a sufficiently high level during the return flight to base, or, in an emergency, during completion of the mission.

Humidity

Most of the time the humidity level was below the measuring capability of the wet-bulb thermometer carried during this evaluation. The maximum humidity recorded was 20 per cent. The predictable effect of this low humidity was confirmed by crew members' reports of frequent upper respiratory infections and nosebleeds during and after long flights.

Toxicology

No hazardous concentrations of carbon monoxide or petroleum hydrocarbons were recorded in the aircraft.

Sanitation

A relief tube urinal is available in the starboard after corner of the aircraft (see Appendix C). This froze during one flight and became unusable. The greatly increased usage of the faeces pail for urination caused overflowing when turbulence was encountered and produced a requirement to empty the pail into plastic garbage bags. It must also be noted that the only facility available for hand-washing was a plentiful supply of "Handi-Wipe" cloths. Therefore, the occurrence of two cases of acute gastroenteritis during the third flight may not be entirely atypical. Clearly, there is an immediate need for a fully equipped lavatory in the aircraft, of the type commonly used by commercial airlines.

Galley Facilities

The provision of food was good, but refrigeration space was inadequate and facilities for preparing hot drinks were acceptable only because the crew in question had supplied their own coffee urn. On the flights originating from CFB Edmonton, milk was provided in "Polygal" containers rather than in individual one-pint containers. This creates inconvenience in the crowded galley area and leads to frequent small spills of milk. While this is more a major irritation than a health hazard, spillage occurring in the heat of summer could create a health hazard.

There is a need for facilities to clean cooking utensils. The galley is too small; this was especially noticable when the ground crew was aboard during the first and third flights, when some crew members spent a considerable proportion of their rest breaks waiting to use the few facilities provided. At times, the galley table was difficult to use for the purpose of eating and drinking, because of its location within the area of maximal noise and vibration (see Appendix C).

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V. HABITABILITY AND CREW FATIGUE ASSESSMENT

by Major J.R. Hodgkinson M.D.

OBJECTIVE

The objective of this investigation was to obtain comprehensive measures of atmospheric temperature and humidity, test for the presence of carbon monoxide and petroleum hydrocarbon fumes, assess sanitation, rest and galley facilities, and observe overt manifestations of clinical illness and severe fatigue which might be causally related to stresses encountered during the missions flown.

PROCEDURE

Atmospheric temperature and humidity were measured with a mercury dry-bulb thermometer and a DREO WBGT thermometer. Atmospheric pollution was measured with a Draeger Gas Detector, Model 19/31, with detector tubes CH206 and CH261. Facilities were evaluated by personal observation and by discussion with the crew, squadron operations staff, and CFHQ DERMA and DFS staffs.

RESULTS

Temperature

Appendix L shows the dry bulb temperatures recorded at various positions in the aircraft after one and one-half hours of the first flight (see Appendix A), when outside air temperature was -31°F.

Appendix M shows temperatures recorded during the same flight after eleven hours, when the outside air temperature was -22°F.

Three things are clear:

a. There is a large vertical gradient in temperature at many positions. This gradient averages 20 degrees (F) over the positions measured after eleven hours, but in extreme cases can be over 40 degrees. Extreme cases are marked with asterisks in Appendix M.

b. There is a pronounced horizontal variation in temperature from one position to another throughout the aircraft, reaching an extreme of 48 degrees.

c. At any given position, there is a variation in temperature during a flight, which is not entirely determined by outside air temperature. On average, this variation is small (less than 10 degrees, but it could amount to 20 degrees (e.g. at the Beam Search Stations)).

Unquestionably, a more efficient method of regulating the production and distribution of heat is required if crew members are to operate efficiently. Maintaining the temperature around an operator's feet at 30°F while his head is surrounded by air at over 70°F is not conducive to the prolonged concentration required at many of the crew stations. The temperature variation between crew-stations also makes it difficult for observers, who rotate among six different stations, to dress appropriately.

During the second flight, an opportunity was taken to test the aircraft's backup heating system. The main heater was turned off and temperatures were sampled after one minute. The backup heater was then switched on and temperatures were sampled after fifteen minutes. On switching off the main heater, temperatures fell drastically; reaching 20°F at floor level on the flight deck after only one

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The second method, to change the display frequency, would require only a minor and therefore inexpensive modification to the sonar set and such a modification might prove quite successful. Preliminary tests with the tape recordings of Argus noise indicate that tone-threshold is at least two orders of magnitude (20 dB) lower at 1850 Hz than it is at 850 Hz. At 1850 Hz the minimum audible sonar return would be on the order of 40 dB and returns above 60 dB would almost certainly be audible. The observer's ability to estimate target speed would be slightly reduced as a result of this increase in frequency. However, it would be a small price to pay for the anticipated improvement in detection capability. And, in point of fact, 1850 Hz is only 100 Hz above the upper display frequency of the Sea King (CHSS-2) helicopter sonar. In an effort to determine the best display frequency for active sonar in the Argus, a testing program has been initiated at DCIEM and a report on the results will be published.

DETRIMENTAL EFFECT OF AMBIENT SOUND ON PASSIVE SONAR

By comparison, the ambient sound has much less effect on the operation of passive sonar, for the simple reason that by far the majority of the passive sonar task is performed visually. The high noise levels in conjunction with the extreme length of Argus patrols undoubtedly lead to a reduction in operator efficiency at the visual task, but that is a different issue (commented on in Section V).

A portion of the passive sonar task is auditory however. The analysis of much of the transient passive information is still done with the ear, and this portion is adversely affected by aircraft noise and power supply hum. The sound emanating from ships and submarines is basically low-frequency, that is, below about 500 Hz. Our preliminary tests show that tone-threshold in the presence of Argus aircraft noise is on the order of 95 dB at 250 Hz. Consequently, only an extremely loud sound from a target would be audible in this frequency region. Thus, in all probability, low frequency transient information cannot be used for purposes of auditory target classification on the Argus. This transient information can be analyzed later on the ground, since a tape recording of the sonobuoy's output is made.

Occasionally observers report hearing reasonably high-frequency sounds associated with submarines (transients and steady state sounds). It is possible that the power supply hum could mask a weak return of this type. This is not a serious problem, in the sense that few detections are likely to depend solely upon power in this frequency region; however, it is a possible source of trouble and it is well within the capability of modern technology to eliminate this artifact.

CONCLUSIONS

The intense low-frequency energy coming from the engines of the Argus will mask most active sonar returns that are less than 70 dB SPL and many that are as much as 80 dB SPL. It would be very difficult to reduce the low-frequency energy reaching the observer's ears, short of replacing the aircraft's engines with jet engines. It would be possible to lower the threshold for detection by about 20 dB, which is a substantial reduction, by increasing the display frequency for the sonar returns to 1850 Hz from the 850 Hz that is presently used.

In addition, the aircraft engine noise adversely affects auditory processing of transient passive sonar information, since it almost completely masks sound in the frequency region below 500 Hz, where most ship and submarine sounds occur. But this is not as serious as the active sonar detection problem, since the passive sonar task is primarily visual.

[redacted]

[redacted]

DETRIMENTAL EFFECTS OF AMBIENT SOUND ON ACTIVE SONAR

Sonar returns are presented to the Sonar Observer using a display frequency of 850 Hz. There is no visual display in the Argus for sonar returns, so all detections must be made on the basis of acoustic information in the 850 Hz region. Figure 15 shows that the noise level at 850 Hz in the ear canal of an observer wearing a well-fitted helmet would be on the order of 18 dB. Threshold for an 850 Hz sinusoid presented to an observer in the presence of a white noise with an 18 dB spectrum level would be about 35 dB. Thus, at first glance, one might be led to suspect that Argus aircraft noise has virtually no detrimental effect on active sonar detections. However, this is not the case. Preliminary tests conducted in the DCIEM sound room indicate that a tone in the 850 Hz region has to be at least 60 dB SPL to be detected about 50 per cent of the times it is presented. These data were obtained by seating subjects with DH41-2 helmets in a sound reproducing room and determining thresholds while the recording of the Argus noise was played back at the original levels. It is the very intense low-frequency components that are doing the masking; that is, preventing detection below the 60 dB level at 850 Hz. This spread of masking is a well-known phenomenon in human hearing. Put simply, and without explanation, a low-intensity, low-frequency sound masks only sound in its immediate vicinity. However, as the intensity of a low-frequency sound is increased the range of frequencies whose threshold is elevated increases disproportionately and low-frequency components on the order of 100 dB disrupt auditory processing dramatically. In fact, Wegel and Lane (1924) showed that a 100 dB, 200 Hz sinusoid elevates the threshold of an 800 Hz sinusoid to around 60 dB which is in close agreement with the present findings.

Thus, sonar returns in the 850 Hz region will not be heard if they are below 60 dB SPL. And it should be pointed out that, for several reasons, this is a very conservative estimate of sonar return threshold. First, the laboratory subjects were well rested and their attention was monitored. Second, the tones used to determine this estimate of threshold were of long duration with respect to sonar pings. This difference would be expected to raise the threshold for sonar returns by at least another 5 dB and possibly as much as 12 dB. Third, when all four engines are in-phase the amplitude of the aircraft noise increases by as much as 10 dB. The observers in the laboratory merely waited for these louder sections of the tape to pass before adjusting the tone to threshold and thus 60 dB is an artificially low estimate because a Sonar Operator cannot choose his time to listen for a return. Thus it seems likely that even an attentive operator would rarely hear a return of less than 70 dB SPL and 80 dB returns would often be missed. It is also important to note that a return has to be on the order of 10 dB above threshold for the observer to be able to make a reasonable estimate of its doppler shift. It is difficult to estimate the proportion of sonar signals that are below 70 or 80 dB SPL when they reach the Sonar Observer's ear. However, it seems likely that a substantial proportion would be masked by the aircraft noise. The Argus then, is not well suited for active sonar work with a display frequency of 850 Hz.

The power supply component at 816 Hz is the only one that could have had a harmful effect on active sonar detections. However it is relatively weak and of no great concern for active sonar.

Potential Solutions to the Active Sonar Problem

Two methods of improving this situation are to reduce the intensity of the low-frequency harmonics found in the aircraft noise and to change the display frequency of the sonar system. The first of these suggestions would, however, be very costly and in all probability only mildly successful. The problem is that the energy doing the masking is very low-frequency. At these frequencies insulation and helmets are not very effective. The only practical way to solve the noise problem would be to either replace the engines, preferably with jet engines, or, in some other fashion, reduce the low-frequency noise levels right at the source.

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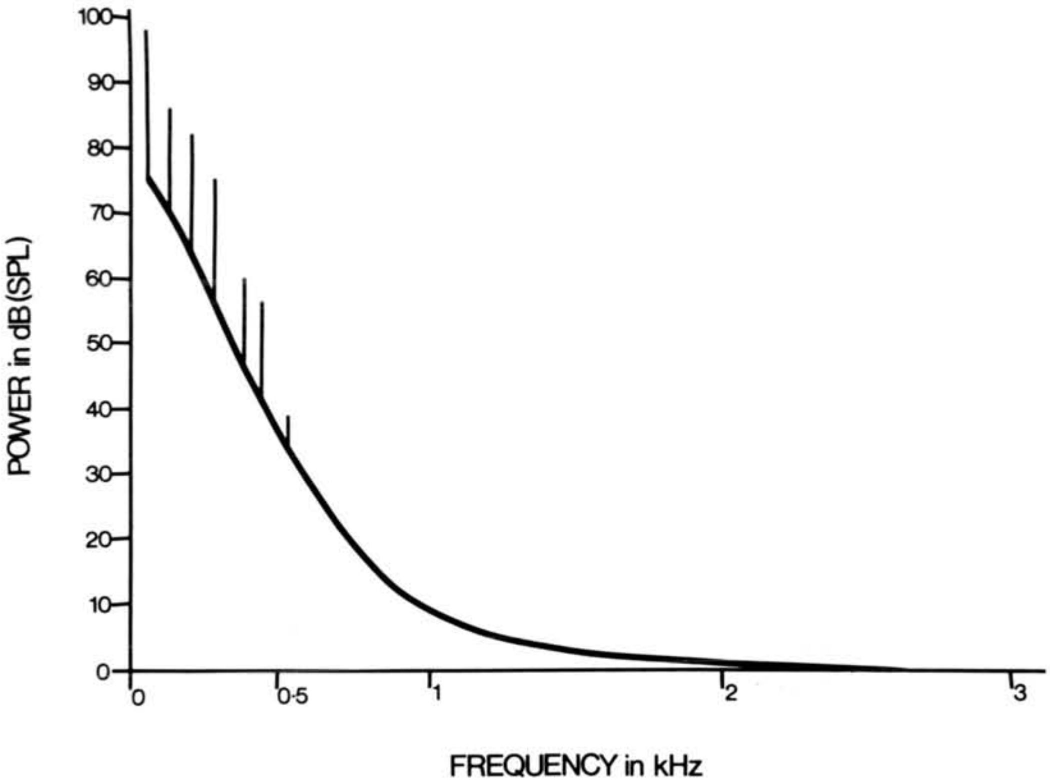

Figure 16. Estimated spectrum of aircraft and communication system noise at the sonar observer's ear.

[redacted]

[redacted]

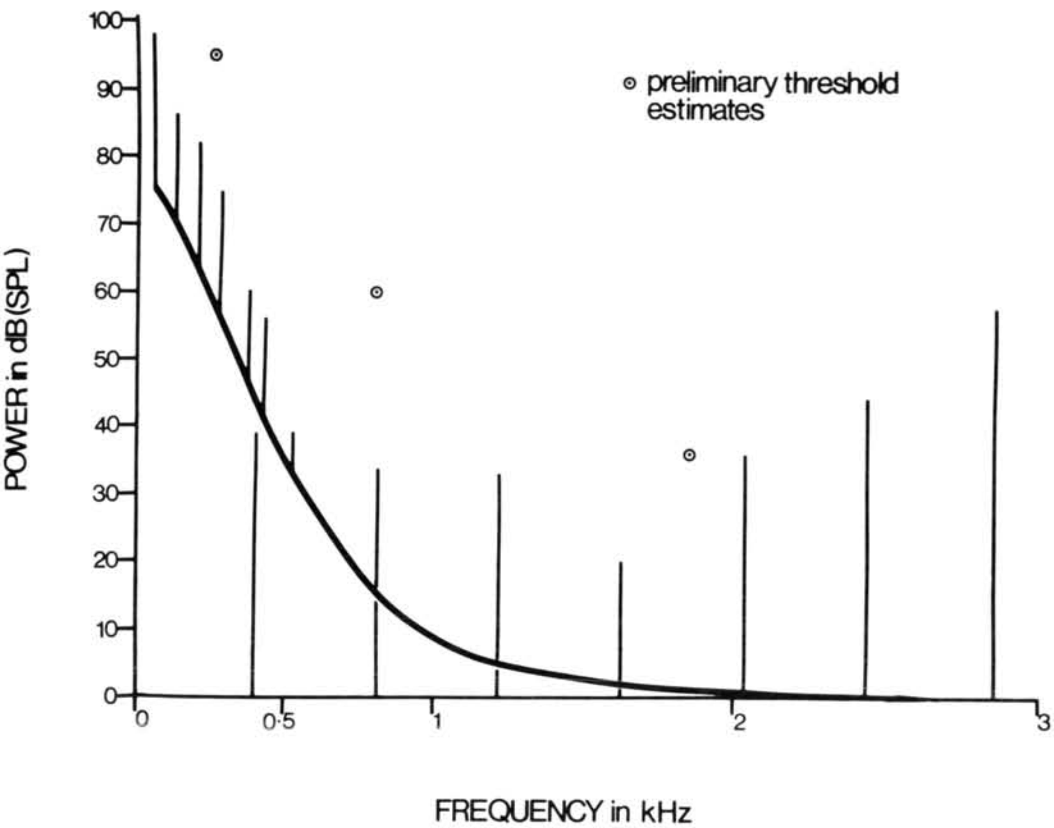

Figure 15. Estimated spectrum of the Argus aircraft noise at the observer's ear.

[redacted]

[redacted]

was inserted in the observer's ear canal and the level of each harmonic of 408 Hz was measured. There are two important reasons for using this entailed procedure. First, it takes account of the non-linear frequency response of the earphone in the DH41-2 helmet, and, second, it reveals the effects of coupling this earphone to the ear canal and pinna.

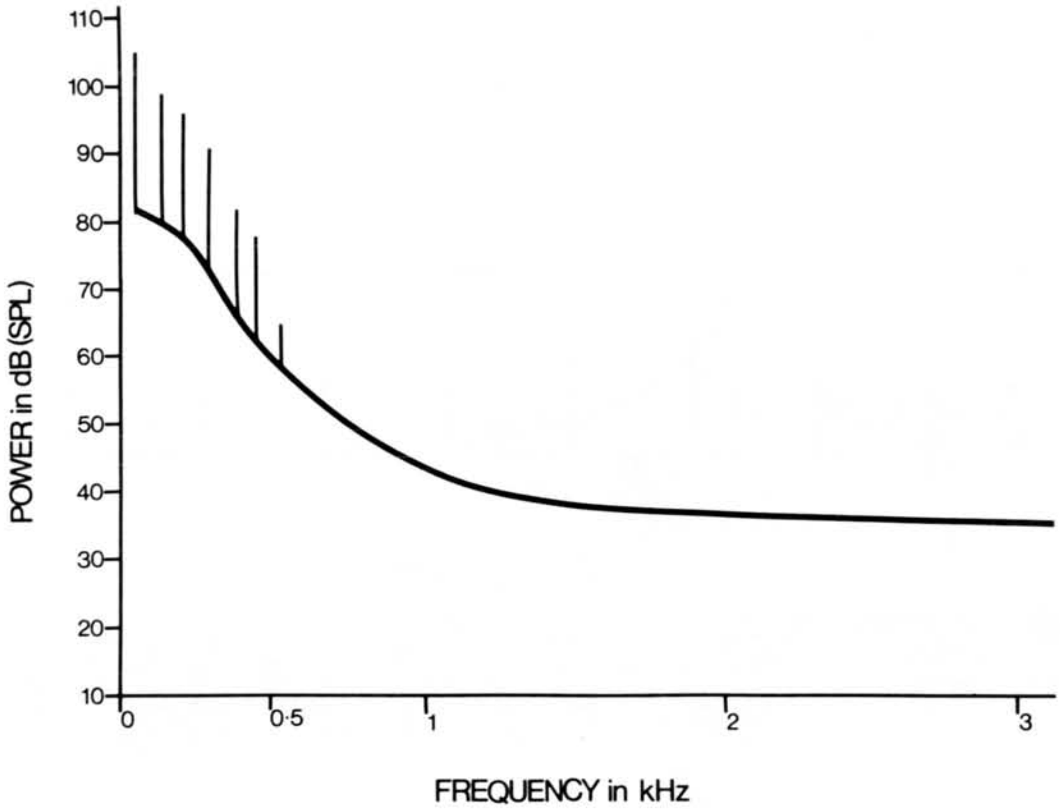

Figure 14. Spectrum of the Argus aircraft noise at the sonar observer's position.

Figure 16 is a copy of Figure 15 to which the harmonics of 408 Hz, as measured with the probe microphone technique, have been added. Thus, Figure 16 is a calculated estimate of the background in which the Sonar Observer must perform his task. The harmonic levels shown in this figure are those obtained with a maximum volume setting. As the volume control is turned down to its minimum the harmonics decrease by about 10 dB.

[redacted]

[redacted]

IV. MASKING OF SONAR SIGNALS

by R.D. Patterson

In the previous section the effects of the aircraft noise on communications and the potential risk to the auditory system of the crew members were discussed. This section deals with the effect of aircraft noise on the Sonar Observer's ability to detect and classify sonar returns.

There are two kinds of unwanted sound reaching the Sonar Operator's ears; aircraft engine noise and communication line electrical noise. In this section the power spectrum associated with these unwanted sound sources is described briefly and then the potential adverse effects of each source on both active and passive sonar are discussed.

AIRCRAFT NOISE AT THE OPERATOR'S EAR

To get an estimate of the power spectrum of the aircraft noise that impinges on the operator's ear, a tape-recording was made of the sound at head level in the Sonar Operator's position while the plane was in flight. The tape was analyzed with a narrow-band (10-Hz bandwidth) wave analyzer (Hewlett Packard 3590A); and then the known (Reference 28) attenuation characteristic of the Gentex helmet (DH41-2) was subtracted from the power spectrum of the recorded noise.

The power spectrum of the aircraft noise as recorded in the Sonar Operator's position is shown in Figure 14. There are no surprises in the spectrum, with the possible exception of the very high levels of the low-frequency components (over 100 dB). The spectrum shows what appears to be a set of odd harmonics of a fundamental in the neighbourhood of 40-45 Hz and a background noise that has a spectrum level of around 80 dB at 200 Hz and which falls from this level at a rate of about 12 dB per octave. This recording was made when the engine speed was 2400 rpm. Recordings were made at lower rpm levels (1900, 2000, 2100 and 2320 rpm) and the spectra associated with slower speeds show slightly lower levels, as can be seen in Figure 13 (see Section III). The spectrum associated with 2400 rpm is presented because the engines are set at 2400 rpm when the Argus is performing a sonar search.

Figure 15 presents the calculated estimate of the aircraft noise spectrum in the observer's ear canal. These data were obtained from Figure 14 simply by subtracting the attenuation characteristic for the DH41-2 helmet.

COMMUNICATION LINE 'NOISE' AT THE OPERATOR'S EAR

When you put on a helmet or headset in the Argus and plug into the AIC/10 communication system, the first thing you hear is a buzzy harsh tone. This tone is produced by a set of harmonics of the 408 Hz power supply that are present on the communication lines throughout the aircraft. The second harmonic of the power supply leakage (816 Hz) is very close, in frequency, to the display frequency of the active sonar (850 Hz) in the Argus. The higher harmonics (3rd-8th) in this set are in the range of speech frequencies. Consequently this background "hum" was tape recorded and analyzed to determine whether it is interfering with the detection of sonar returns or the processing of speech.

The following is a description of the procedure used to obtain an estimate of the levels of the harmonics reaching the observer's ears. A tape recording was made of the hum on the tactical intercommunication line while the aircraft was in flight, that is, a recording of the electrical signals. Later, in the laboratory, this recording was played to an observer wearing a DH41-2 helmet. Finally a probe microphone

[redacted]

[redacted]

CONCLUSIONS

1. The noise within the aircraft is predominantly low frequency. The risk of hearing loss is minimal for crew members who wear effective hearing protection and routinely work away from areas of maximum noise.

2. The Radio Operator is located in the worst possible area of the aircraft. Noise masking is such that the receiver amplifier-gain must be set to a fairly high level in order that an individual may hear incoming signals, and the resulting aircraft and receiver noise levels under the flight helmet earphones are so intense that daily continuous exposures in excess of 14 minutes constitute a potential long-term hazard to hearing.

   The degree of this hazard can be reduced somewhat if the Radio Operator wears a pair of properly fitted ear plugs under his headset. If this is done speech intelligibility may increase slightly, depending on the degree to which the levels of the speech and noise are reduced within the overload region of the auditory system.

3. Voice communications within the aircraft, using the AIC/10 system, are not seriously hampered by noise when engine speed is not greater than about 2200 rpm. At speeds greater than this (e.g., during takeoff or tactical operations) communication efficiency may be reduced.

4. Moderately high levels of vibration occur in the structures (desks and tables) in close proximity to the aircraft engines. The application of suitable isolators on these structures should reduce the effects of secondary vibration exposure upon the crew, and control the re-radiation of noise within the aircraft.

[redacted]

helmet and M-87 noise-cancelling microphone, (b) the AIC/10 communication system, and (c) the speech-test listener, wearing either the Gentex flight helmet or the Roanwell H-157/AIC headset, located in the same general area as the speech-test talker. Three crew members acted as speech-test listeners. They were each tested twice at both locations.

The results of the intelligibility tests are shown in Appendix J and indicate that the scores for this type of speech-test stimulus ranged from 89 to 100 per cent correct. Clearly, there was no significant difference in intelligibility between the two crew-work locations, and these results confirm the general observation that voice intercommunication within the aircraft is not a problem, at least for long-range cruise engine-speed (rpm < 2200)[8].

VIBRATION LEVELS

In general, large airframe resonances occur at least one decade lower in frequency ($f < 10$ Hz) than aircraft engine excitations. It is essential, therefore, that vibration measuring equipment have response characteristics down to zero frequency. The frequency-response characteristics of the equipment used in this study for vibration measurements did not meet this requirement[9] as the primary requisite for the equipment was portability and battery operation. Consequently, the observations and discussions contained herein are restricted to 'high frequency' vibrations ($f > 20$ Hz).

Vibration measurements were made at a number of crew work- and rest-areas throughout the aircraft. The use of resilient components (seat cushions, bunk mattresses) appears to reduce to an acceptable level the transmission of vibratory energy to the man occupying a seat or bunk. Indeed, levels of acceleration in excess of the recommended limits for z-axis exposure (ISO, 1970) were not observed when a rigid transducer support was interposed between the contact area of the man and the resilient component. Comments solicited from the crew tend to confirm this conclusion (see Section II) in that references to seat discomfort do not mention symptoms typical of a lack of effective vibration isolation (e.g., 'pins and needles' or paresthesia in contact areas).

The acceleration levels shown in Appendix K pertain primarily to structures (control consoles, desk and table tops, window ledges) on which secondary vibration effects usually occur. Crew complaints are most specific regarding vibrations on these surfaces: books, pencils, plates etc., continually bounce across and fall from the tables and desks in the Galley, Routine Navigator, and Radio Operator areas.

The octave-band acceleration data indicate that the principal frequencies of vibration in these structures are above 100 Hz. Vibration effects at these frequencies are highly dependent upon local factors such as the direction of the vibration, the site and area of application of the vibration to the body, and the presence of damping materials (e.g., clothing) which may control the vibration response of the skin and superficial layers of the body (ISO, 1970).

Suffice it to say that moderately high levels of acceleration occur in the panels and structures of the aircraft in close proximity to the engines. The application of suitable isolators on these structures should reduce the effects of secondary vibration exposure upon the crew, and control the re-radiation of noise within the aircraft.

---

[8] Excessive noise is, however, mentioned by one or more of the crew (see Section II, Pilot, ASW Stores Launch Area, MAD/Julie Operators' area) in connection with poor intercommunications in the cockpit during take-off (rpm > 2400), during tactical operations in the Tactical Compartment (rpm $= 2400$), and in the ASW Stores Launch Area when the launch chutes are open.

[9] See Appendix F for the noise and vibration measuring and calibration equipment.

[redacted]

It is interesting to note that of the five crew members (Nos. 4, 6, 8, 10 and 12 (see Appendix H)) who spent one or more of the last four hours of the second flight in the maximum noise areas of the aircraft (Galley, Navigator, Radio Operator areas), three sustained significant TTS and one had elevated pre-flight hearing thresholds (i.e., permanent hearing loss) that would probably preclude significant TTS. Further, two of the individuals exhibiting significant TTS (Nos. 10 and 12) worked one and three hours respectively as Radio Operator.

HEARING LOSS AND FLYING EXPERIENCE

The pre-flight hearing thresholds of the aircraft crew of this study do not correlate with accumulated flying times. Only two of the five individuals having flying times greater than 5000 hours (Nos. 2 and 4 (see Appendix H)), and one of the six persons with times less than 2000 hours (No. 8), show signs of an onset of significant permanent hearing loss. Such hearing loss depends, of course, on a number of factors. Occupational noise exposure is usually the prime contributor to inner ear pathology, especially if the exposure is sufficiently severe and/or of a continuing long-term nature. Other factors which may be equally important, however, include non-occupational noise exposure, physiological aging (presbycusis), certain illnesses, drugs and accidents etc., and the general susceptibility of the individual to noise-induced hearing loss.

In a study of the hearing acuity of crews of the Lockheed Orion (P-3A and P-3B), Pierson and Barron (1969) have obtained similar results. Their clinical and statistical evaluations indicate that no permanent hearing loss can be attributed to the noise exposure experienced in long range patrol aircraft. They cannot discount the possibility, however, that experienced aircrew (e.g., persons with flying time exceeding 4000 hours) represent a select population with lower than normal susceptibility to noise-induced hearing loss, and that such hearing loss eliminates the normal and overly susceptible individuals before they can accrue many flying hours.

RADIO OPERATOR NOISE PROBLEMS

Clearly, the Radio Operator is located in the worst possible area of the aircraft. Noise masking is such that the receiver amplifier-gain must be set to a fairly high level in order that an individual may hear incoming signals, and the resulting sound pressure levels at the operator's ears are 90 and 100 dB respectively for signals and static (see Appendix I). Indeed, the combined aircraft and receiver noise levels under the flight helmet earphones are so intense that daily continuous-exposures in excess of 14 minutes constitute a potential long-term hazard to hearing (Forshaw, 1970). However, the degree of this hazard can be reduced somewhat (the non-hazardous continuous-exposure time can be increased to approximately two hours) if the Radio Operator wears a pair of properly fitted ear plugs under his headset. That is, by further reducing the level of aircraft noise reaching the inner ear (at least to the limit where bone conduction occurs), the ear plugs also reduce the receiver signal and noise levels required to maintain a given signal-to-aircraft-noise ratio at the inner ear. In addition, speech intelligibility may increase slightly, to the extent to which the levels of the speech and noise are reduced from within the overload region of the auditory system.

SPEECH INTELLIGIBILITY

Multiple-choice speech intelligibility tests (Black, 1957) were conducted at two crew-work locations in the Argus: (1) an area of maximum noise (the Routine Navigator/Radio Operator area) and (2) an area of less intense noise (the ECM Operators' area). The speaker-listener link under evaluation included (a) the speech-test talker, located in one of the two crew areas (ambient sound pressure level = 110 and 105 dB respectively, at engine speeds of 2100-2200 rpm), wearing the Gentex DH 41-2 flight

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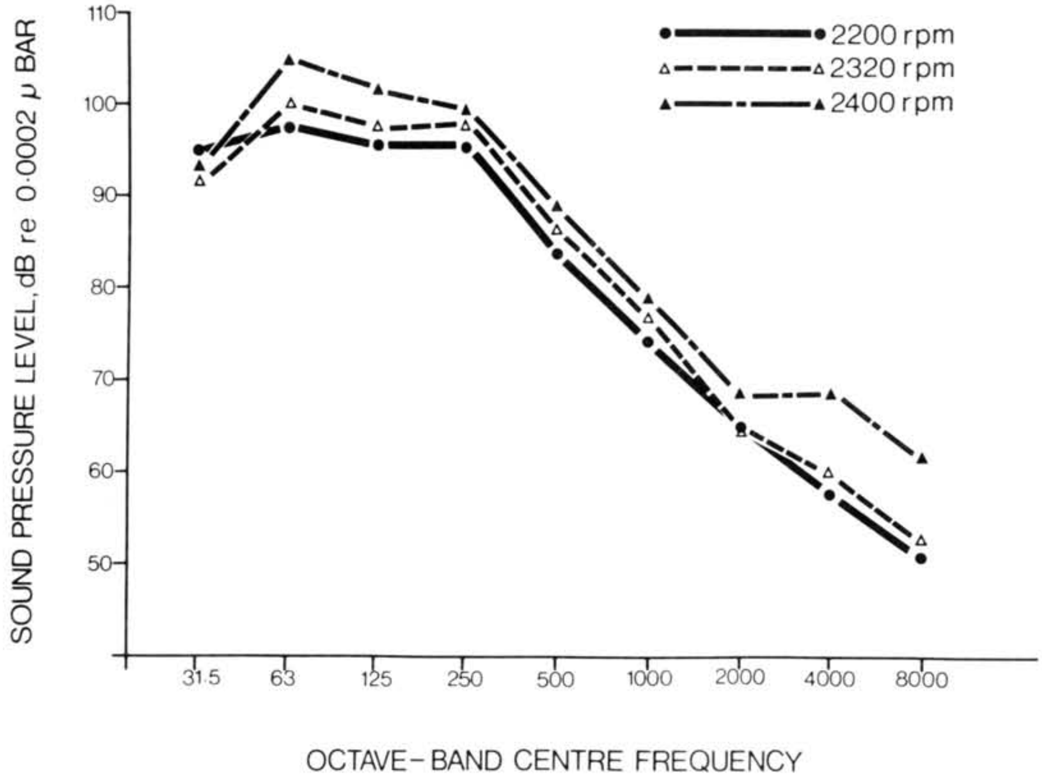

Figure 13. Octave-band sound pressure levels at the MAD Operator location in the Argus aircraft as a function of engine speed.

The noise exposure experienced by an individual may be considered potentially hazardous in the long term if the TTS thus sustained exceeds 15 dB at 2000 Hz, or 20 dB at 3000 Hz, 4000, or 6000 Hz in one or both ears[6, 7]. Nine crew members exhibited TTS in excess of this criterion (Nos. 1, 3, 9, 10 and 14, left ear; Nos. 2, 4, and 15, right ear; No. 12, both ears (see Appendix H)) at one or more of the audiometric test frequencies. However, the pre-flight hearing thresholds of six of the crew (Nos. 2, 8, and 15, left ear; Nos. 9 and 14, right ear; No. 5, both ears) were already in excess of the above criterion to probably preclude indications (TTS) of significant trauma that would otherwise be manifest from an intense noise exposure.

---

(6) In this study, a TTS of ±10 dB is not considered significant. The pre- and post-flight audiograms were obtained with different audiometers and operators in rooms where outside noises interfered intermittently with the test signals.

(7) The CHABA damage-risk criterion for steady-state noise considers a permanent hearing loss to be acceptable, after many years of noise exposure, it it does not exceed 10 dB at or below 1000 Hz, 15 dB at 2000 Hz, and 20 dB at or above 3000 Hz (CHABA, 1965).

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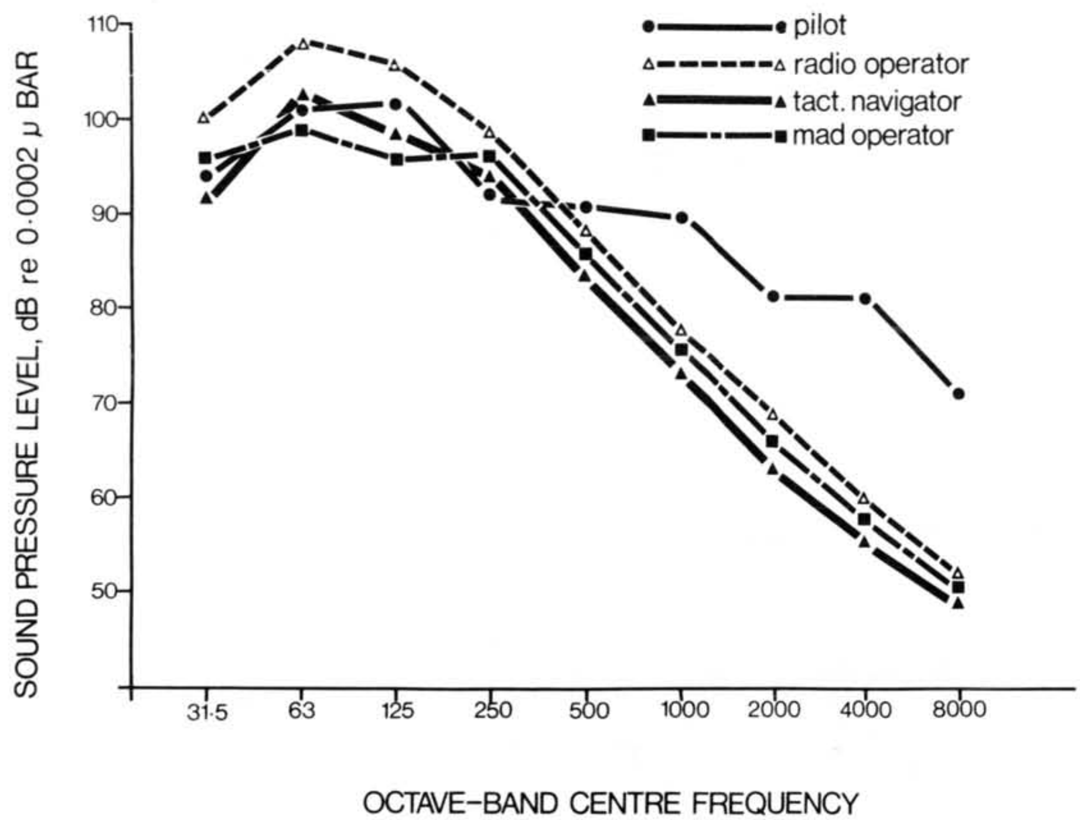

Figure 12. Octave-band sound pressure levels at four crew work locations in the Argus aircraft (engine speed = 2100-2200 rpm).

NOISE EXPOSURE: SHORT-TERM EFFECTS

Temporary Threshold Shift (TTS) measurements were made on the 15 crew members of the Argus aircraft to ascertain whether long duration exposures to the noise of the aircraft are in fact potentially hazardous to hearing[4]. Hearing thresholds were obtained at CFB Greenwood prior to take-off of the first 16-hour flight, and within 90 minutes of landing at CFB Namao after the second 16-hour flight[5]. The results of these audiometric tests are shown in Appendix H; the TTS sustained at a given frequency is the difference in dB between the pre- and post-flight hearing thresholds at that frequency.

---

(4) The immediate effect of high intensity sound upon the auditory system is a threshold shift; it is the difference in an individual's hearing threshold before and after a sound exposure. This change in sensitivity of the ear to just detect a pure tone of a given frequency is temporary, and is thus called temporary threshold shift, or TTS. The recovery time-constant is such that a TTS not greater than about 40 dB will disappear in less than 24 hours. Continual exposure over a period of years to sound of sufficient intensity will eventually result in the inability of the ear to recover its pre-exposure hearing threshold; that is, the TTS gradually becomes permanent. It is therefore assumed that noise exposures which produce given amounts of TTS (measured two minutes after an exposure) eventually produce, if repeated on a near-daily basis for a number of years, approximately the same amount of permanent hearing loss. TTS is accepted, then, as a measure of the damage that is sustained by the ear from exposure to high intensity noise.

(5) A 36-hour stop-over occured at CFB Edmonton (Namao) between the first and second 16-hour flights. The TTS observed after the second flight is attributed, therefore, to the noise exposure experienced only during the second flight.

[redacted]

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III. NOISE AND VIBRATION ASSESSMENT

by S.E. Forshaw

The noise and vibration levels in the Argus aircraft are assessed in this section as they relate to (1) the immediate and potential long-term effects of exposure to the noise on the hearing mechanism, (2) the speech interference effects of the noise, and (3) the effects of the vibration on aircraft personnel. The possible interference effects of the noise on the auditory discrimination and detection tasks associated with the aircraft tactical operations are reported in Section IV.

NOISE LEVELS

Noise levels were measured at all crew work- and rest-locations in the Argus aircraft as a function of engine speed[1]. Maximum levels were observed at areas close to the plane of the propellers (Galley, Radio Operator, Routine Navigator) and ranged from 100 dB at 1900 rpm (Thrasher and Killoran, 1959) to 113 dB at 2320 rpm (see Appendix C). The areas of least noise were the Tactical Compartment and the ASW Launch Area; at these locations the noise levels varied from 100-101 dB at 1900 rpm to 104-109 dB at 2320 rpm.

Appendix G presents the octave-band sound pressure levels in the Argus aircraft as a function of location in the aircraft and selected engine speeds. These data indicate that the noise is predominantly low frequency ($f < 250$ Hz). The spectral distribution of the noise is shown in Figure 12 at four typical locations in the aircraft. Maximum low-frequency energy is encountered at the Radio Operator's position, and considerable mid-frequency energy is generated in the cockpit by high-velocity air flow from air conditioning outlets and/or across the windscreen. Octave-band noise levels at the MAD Operator's position are shown in Figure 13 as a function of engine speed.

NOISE EXPOSURE: LONG-TERM HEARING RISK

Calculations based on (1) the octave-band noise data for the Argus aircraft (see Appendix G), (2) the pure-tone sound attenuation characteristics of the Gentex DH41-2 flight helmet (see ref. 28), and (3) the Canadian Forces damage-risk criterion for steady-state noise (Forshaw, 1970) indicate that the risk of hearing loss due to long-term noise exposure in this aircraft is minimal for crew members who wear effective hearing protection[2] and routinely work away from the areas of maximum noise[3]. Noise exposures in excess of one-half and two hours, respectively, in the Routine Navigator and Radio Operator areas, are potentially hazardous to hearing at high engine speeds (rpm > 2300), even for personnel wearing properly fitted headsets or flight helmets. However, periods of high engine speed do not normally exceed one to two hours on long range patrol and reconnaissance flights.

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(1) See Appendix F for the noise and vibration measuring and calibration equipment.

(2) Roanwell Corp. H-157/AIC headset (ref. 34), V-51R ear plug (ref. 33), EP100 ear plug (ref. 29), or the SSC 258 earmuff (ref. 31).

(3) Not all personnel do, in fact, wear hearing protection continuously (e.g., during sleep and off-duty periods). Moreover, some equipment is used (e.g., headset NSN 5965/00/504/7598) that does not provide optimum protection from noise.

[redacted]

[redacted]

It can therefore be seen that there are two very different approaches to the problem of improving crew/station interfaces in the Argus aircraft:

1. Making use of the short-term improvements listed above for each crewstation, which would correct the more glaring errors in human engineering. These recommendations are virtually restricted to improvements in seating comfort, removal of redundant hardware, and relocation of the more inaccessible displays and controls. The effect of these improvements on efficiency of performance will be strictly limited, because most tactical stations are comprised of separate items of equipment, each having its own display and control surfaces, from which components cannot readily be moved. It is clear that well human engineered crewstations cannot be constructed by *post hoc* modifications to workspaces laid out on the engineering design concept.

2. The alternative approach is to dismantle all tactical crewstations and reassemble the components on the human engineering design concept outlined above. Clearly the cost-effectiveness of this approach in the present instance would be minimal, in view of the outdated hardware involved. There would, in any case, be minimal gain from this approach, because of the severe problems of noise and vibration with the aircraft.

These problems would also limit any gain in operational efficiency which might be obtained by refitting tactical crewstations with entirely new and updated equipment.

The final conclusion must be that, although comfort and performance could undoubtedly be improved by the application of some simple human engineering to the crew/station interfaces, substantial gains could be achieved only be replacing the complete aircraft with an alternative which was designed *ab initio* on human factors criteria.

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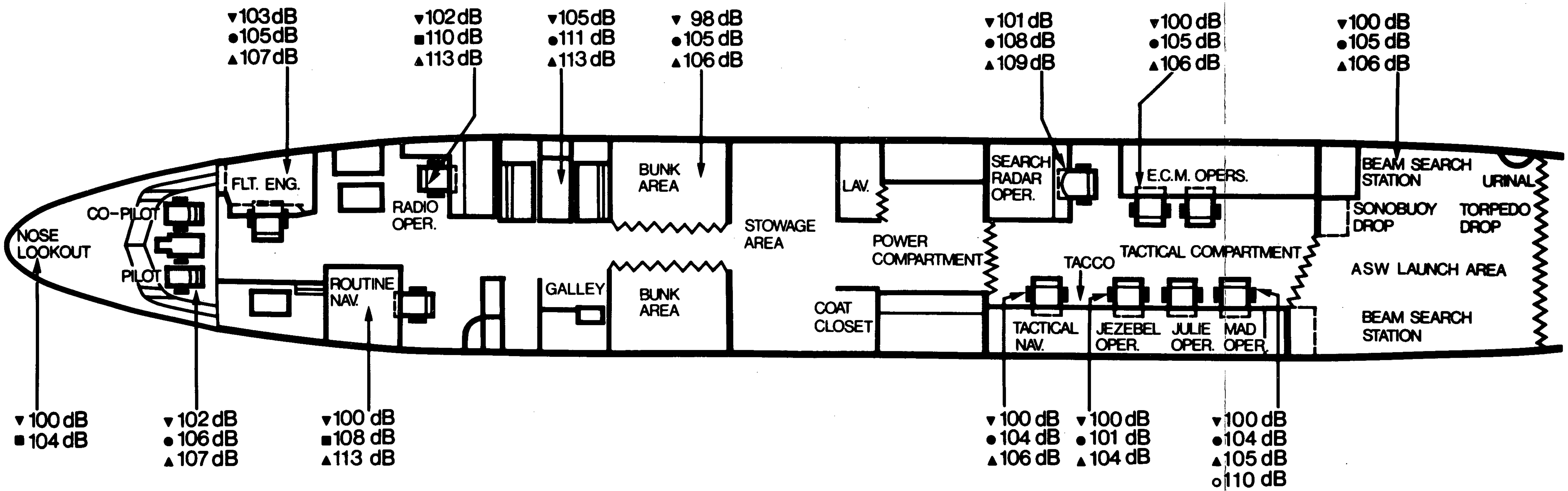

ENGINE SPEEDS

▼ 1800 – 1900 rpm (THRASHER and KILLORAN, 1959)
■ 2100 rpm
● 2200 rpm
▲ 2320 rpm
○ 2400 rpm

APPENDIX C: PLAN VIEW OF THE ARGUS AIRCRAFT SHOWING THE CREW WORK AND REST AREAS AND OVERALL SOUND PRESSURE LEVELS.

[redacted]

[redacted]

APPENDIX D

HUMAN FACTORS QUESTIONNAIRE

INTRODUCTION

The following questionnaire has been designed to gather the flight crew's assessments of their aircraft. A similar questionnaire was used extensively in the evaluation of the British VTOL, the Hawker Harrier.

Laboratory testing and simulator studies by professional investigators supply most basic design data on modern aircraft. Test pilots supply the majority of information pertaining to flight handling characteristics and the suitability of the cockpit layout. It has, however, become increasingly important that the actual users, the professionals who must fly the aircraft on a day to day basis, have the opportunity to present an assessment of the suitability of the aircraft for their particular duties.

It should be stressed that this questionnaire is being used to assess the work space design of the aircraft and not to assess the flight crew's ability to write an assessment. In the final report there will be total anonymity as to the individual's responses. The purpose of this study is to uncover any possible characteristics of the aircraft which are agreed upon by a number of operators as being unpleasant or troublesome.

[redacted]

[redacted]

APPENDIX D (cont'd)

DATE ____________________

FLIGHT CREW INFORMATION

1. AIRCRAFT TYPE ______________________________

2. FLIGHT CREW POSITION ______________________________

3. RANK ______________________________

4. AGE ______________________________

5. HEIGHT ______________________________

6. WEIGHT ______________________________

7. NUMBER OF MISSIONS FLOWN
   ON THIS AIRCRAFT (APPROX) ____________________

8. NUMBER OF HOURS FLOWN
   ON THIS AIRCRAFT (APPROX) ____________________

9. BRIEF SUMMARY OF PREVIOUS FLYING EXPERIENCE WITH A LIST OF
   PRINCIPAL TYPES OF AIRCRAFT FLOWN

   ____

   ____

   ____

   ____

[redacted]

APPENDIX D (cont'd)

WORK SPACE LAYOUT

1. Are there any instruments you find difficult to read or confusing?
   If so, what are they and why do you consider them inefficient or unclear?

2. Are there any faults in the layout of the instrument panels?
   Are there any additional instruments which you feel are needed?
   If so, what are they and how do you consider they should be rectified?

3. Are all the controls (including critical push buttons and switches) well designed and easy to reach and to operate?
   If not, please describe the faults and any suggestions for improvements.

4. Is the layout of controls satisfactory?
   If it is not, how do you feel it could be improved?

5. Do you find any obstructions or clearance problems in the workspace, i.e., head clearance, shoulder clearance?
   Is there a possibility of accidentally actuating any controls?

6. Are there any other aspects of the work space environment which you feel deserve comment including temperature, noise, vibration, or any safety or comfort problem?

7. Are there any other aspects of your flight equipment (clothing, helmet, oxygen mask, etc.), which you feel are unsatisfactory?

[redacted]

[redacted]

APPENDIX E

ROTATIONAL MANNING OF CREWSTATIONS

CREW	NO. OF MEN	CREWSTATIONS MANNED IN ROTATION					
Flight Engineer	2	Flight Engineer					
Pilot	3	Pilot*	Co-Pilot*				
Navigator	4	Routine Navigator	Tactical † Navigator	Tactical † Co-ordinator	Jezebel Operator	Lookout	
Observer	6	Radio Operator	Radar Operator	E.C.M.	MAD/Julie	Lookout	ASW Stores Launcher

* Pilots completed one combined questionnaire on both stations.

† Navigators completed one combined questionnaire on both stations.

[redacted]

APPENDIX F

NOISE AND VIBRATION MEASUREMENT EQUIPMENT

Sound Measuring Equipment

1. Bruel and Kjaer Sound Level Meter Type 2203.

2. Bruel and Kjaer Octave Filter Set Type 1613.

3. Kudelski Nagara IV S Tape Recorder.

4. Muirhead Probe Microphone Type H112.

Vibration Measuring Equipment

1. Bruel and Kjaer Accelerometer Type 4332.

2. Bruel and Kjaer Integrator Type ZR 0020 for use with Sound Level Meter Type 2203.

Calibration Equipment

1. Bruel and Kjaer Pistonphone Type 4220.

2. Bruel and Kjaer Calibration Exciter Type 4290.

[redacted]

APPENDIX G

OCTAVE-BAND SOUND PRESSURE LEVELS

MEASUREMENT LOCATION, ENGINE SPEED, ETC.	OCTAVE-BAND CENTRE FREQUENCY SPLs dB									OVERALL SPLs	
	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	dBC	dBA(1)
NOSE OBSERVER, FAN ON, 2100 RPM.	98 ±1	96 ±2	93 ±1	97 ±2	93 ±1	86 ±1	84 ±1	72 ±1	67 ±1	104 ±1	93 ±1
PILOT, A/C ON, 2200 RPM.	94 ±4	101 ±5	102 ±2	93 ±2	92 ±1	90 ±1	82 ±1	82 ±1	71 ±1	106 ±2	95 ±2
FLIGHT ENGINEER, 2200 RPM.	95 ±3	101 ±1	101 ±1	95 ±1	88 ±1	84 ±1	72 ±1	68 ±1	62 ±1	105 ±2	91 ±2
FLIGHT ENGINEER, 2320 RPM.	92 ±2	102 ±4	104 ±2	96 ±3	90 ±1	85 ±1	74 ±1	68 ±1	62 ±1	107 ±2	92 ±2
ROUTINE NAVIGATOR, 2100 RPM.	99 ±4	103 ±3	100 ±2	99 ±1	88 ±1	78 ±1	71 ±1	64 ±1	56 ±1	108 ±2	93 ±2
ROUTINE NAVIGATOR, 2320 RPM.	99 ±4	106 ±5	105 ±4	111 ±1	97 ±2	88 ±2	77 ±1	69 ±1	58 ±1	113 ±2	99 ±2
RADIO OPERATOR, 2100 RPM.	100 ±5	108 ±4	106 ±4	97 ±1	87 ±1	76 ±1	69 ±1	60 ±1	53 ±1	110 ±3	93 ±3
RADIO OPERATOR, 2320 RPM.	96 ±4	110 ±5	108 ±3	104 ±2	93 ±1	82 ±1	73 ±1	65 ±1	58 ±1	113 ±2	98 ±2
GALLEY, AFT SEAT, CENTRE OF TABLE, 2200 RPM.	101 ±3	107 ±3	105 ±3	100 ±2	87 ±2	77 ±2	68 ±2	60 ±1	53 ±1	111 ±2	94 ±2
BUNK AREA, AFT STBD, 2200 RPM.	95 ±4	102 ±4	100 ±2	93 ±1	82 ±1	72 ±1	63 ±1	58 ±1	50 ±1	105 ±2	88 ±2
BUNK AREA, AFT STBD, 2320 RPM.	97 ±4	102 ±5	99 ±3	97 ±1	86 ±1	76 ±1	67 ±1	60 ±1	52 ±1	106 ±3	88 ±3
SEARCH RADAR OPERATOR, 2200 RPM.	94 ±4	102 ±4	102 ±4	100 ±1	88 ±1	78 ±1	70 ±1	62 ±1	53 ±1	108 ±2	93 ±2
SEARCH RADAR OPERATOR, 2320 RPM.	93 ±3	102 ±5	104 ±1	94 ±2	89 ±1	80 ±1	68 ±2	57 ±1	50 ±1	109 ±3	92 ±3

[redacted]

APPENDIX G (cont'd)

OCTAVE-BAND SOUND PRESSURE LEVELS

MEASUREMENT LOCATION, ENGINE SPEED, ETC.	OCTAVE-BAND CENTRE FREQUENCY SPLs dB									OVERALL SPLs	
	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	dBC	dBA[1]
TACTICAL NAVIGATOR, 2200 RPM.	93 ±3	102 ±3	99 ±3	95 ±1	85 ±1	74 ±2	64 ±1	57 ±2	49 ±1	104 ±2	89 ±2
TACTICAL NAVIGATOR, 2320 RPM.	94 ±2	100 ±5	101 ±3	96 ±1	88 ±1	75 ±2	65 ±1	57 ±1	50 ±1	106 ±3	93 ±3
FRWD ECM OPERATOR, 2200 RPM.	100 ±5	100 ±4	100 ±3	95 ±3	84 ±1	73 ±2	64 ±1	58 ±2	51 ±1	105 ±3	89 ±3
FRWD ECM OPERATOR, 2320 RPM.	91 ±1	100 ±5	97 ±2	97 ±1	87 ±2	76 ±2	67 ±2	57 ±1	54 ±1	105 ±3	90 ±3
JEZEBEL OPERATOR, 2200 RPM.	93 ±5	97 ±5	95 ±3	95 ±2	83 ±1	74 ±1	65 ±1	59 ±1	54 ±2	101 ±3	88 ±3
JEZEBEL OPERATOR, 2320 RPM.	92 ±2	105 ±5	100 ±5	97 ±2	87 ±1	77 ±1	69 ±3	62 ±2	52 ±2	104 ±2	93 ±2
MAD OPERATOR, 1900 RPM.	96 ±2	96 ±3	97 ±2	98 ±2	85 ±1	77 ±1	68 ±1	56 ±1	51 ±1	103 ±2	90 ±2
MAD OPERATOR, 2200 RPM.	95 ±5	99 ±3	97 ±5	97 ±2	85 ±1	75 ±1	66 ±1	59 ±1	51 ±1	104 ±3	90 ±3
MAD OPERATOR, 2320 RPM.	92 ±2	100 ±4	98 ±3	99 ±2	86 ±1	76 ±1	66 ±1	60 ±1	52 ±2	105 ± 2	90 ±2
MAD OPERATOR, MAX TORQUE, 2400 RPM.	94 ±2	106 ±4	101 ±1	100 ±1	88 ±1	78 ±2	68 ±2	68 ±2	61 ±2	110 ±3	93 ±2
BEAM SEARCH STATION PORT, 2200 RPM.	96 ±3	101 ±2	99 ±3	92 ±2	83 ±1	76 ±1	69 ±1	64 ±1	58 ±1	105 ±1	88 ±1
BEAM SEARCH STATION PORT, 2320 RPM.	96 ±1	104 ±4	95 ±3	92 ±2	86 ±1	82 ±1	73 ±1	68 ±1	60 ±1	106 ±3	99 ±3

(1) A weighting network is an electrical network incorporated in the amplifiying circuit of a measuring instrument (e.g., sound level meter) to produce a specified electro-acoustic frequency response. An "A" weighting network, for example, approximates the 40-phon equal loudness contour, while the "C" weighting network approximates a uniform response in the frequency band from about 50 to 10,000 Hz. The sound pressure level of a sound, expressed in dB, is assumed to be C-weighted unless specified otherwise. Sound pressure levels with A-weighting are expressed as dBA.

[redacted]

APPENDIX H

ARGUS – CREW NOISE EXPOSURE HISTORIES AND HEARING THRESHOLD DATA

NUMBER	CREW POSITION	AUDIOMETRIC TEST TIME	HEARING THRESHOLD LEFT EAR[5] 2KHZ	3KHZ	4KHZ	6KHZ	HEARING THRESHOLD RIGHT EAR[5] 2KHZ	3KHZ	4KHZ	6KHZ	AGE	CREW LOCATION, LAST FOUR HOURS OF NOISE EXPOSURE. (SEE FOOTNOTE 1 FOR LEGEND)	CAREER FLYING HOURS (SEE FOOTNOTE 2 FOR LEGEND)
1	PILOT	PRE-FLIGHT POST-FLIGHT	5 15	0 20	20 20	10 25	0 5	0 5	0 5	10 10	37	2 hrs. (FD), 2 hrs. (AS).	250(HAR), 75(NOR), 4500(DAK), 1300(LAN), 2200(BEE), 1700(ARG).
2	PILOT	PRE-FLIGHT POST-FLIGHT	0 5	10 20	35 25	25 25	0 0	10 15	5 10	10 25	37	4 hrs.(FD).	5200(NEP, ORN), 1500 (ARG)
3	PILOT	PRE-FLIGHT POST-FLIGHT	0 10	5 10	10 15	15 25	0 0	0 0	0 0	0 10	26	2 hrs.(FD), 1 hr.(GA) 1 hr.(FD).	350(EXP, TUT), 1100(DAK), 2000(ARG).
4	NAVIGATOR[4]	PRE-FLIGHT POST-FLIGHT	10	10	25	15	5 20	10 30	25 35	25 35	39	4 hrs.(NR).	1800(NEP), 200(H44), 100(OTT), 300(DAK), 200(EXP), 600(LAN), 1000(ALB), 1200(ARG).
5	NAVIGATOR	PRE-FLIGHT POST-FLIGHT	20 20	20 25	20 20	20 25	20 20	20 20	20 20	20 25	30	4 hrs.(AS).	300(EXP,DAK,NEP), 3100(ARG).
6	NAVIGATOR	PRE-FLIGHT POST-FLIGHT	10 10	15 15	5 10	5 20	0 0	5 5	10 5	10 15	38	4 hrs.(NR).	2200(BOX), 1000(DAK), 2200(YUK), 2700(NOR), 1200(ARG).
7	NAVIGATOR	PRE-FLIGHT POST-FLIGHT	0 0	0 0	0 10	0 10	0 0	0 0	0 0	0 5	23	½ hr.(GA), 3½ hrs.(AS).	200(DAK), 500(ARG).
8	OBSERVER[3]	PRE-FLIGHT POST-FLIGHT	0 0	10 15	40 30	50 40	0 0	0 5	10 10	10 15	25	1 hr.(GA), 2 hrs.(NR), 1 hr.(AS).	110(DAK), 1690(ARG).
9	OBSERVER[3]	PRE-FLIGHT POST-FLIGHT	5 5	5 10	10 15	10 25	0 0	0 0	10 5	20 25	26	2 hrs.(NO), 2 hrs.(AS).	1000(TRA), 900(ARG).
10	OBSERVER[3]	PRE-FLIGHT POST-FLIGHT	0 10	0 20	5 40	5 20	5 10	0 5	10 20	0 15	35	3 hrs.(AS), 1 hr.(RO).	40 (DAK), 1200(ARG).
11	OBSERVER[3]	PRE-FLIGHT POST-FLIGHT	0 5	0 10	0 10	5 20	0 5	0 5	10 10	5 20	27	2 hrs.(AS), 2 hrs.(NO).	50(DAK), 1400(ARG).
12	OBSERVER[3]	PRE-FLIGHT POST-FLIGHT	0 15	15 40	25 45	15 35	0 0	5 35	0 30	35 40	29	3 hrs.(RO), 1 hr.(GA).	400(ARG).
13	OBSERVER[3]	PRE-FLIGHT POST-FLIGHT	5 10	0 0	10 10	10 5	0 0	0 5	10 15	5 20	39	4 hrs.(AS).	2000(NEP, SHA), 2500(ARG).
14	FLIGHT ENGINEER	PRE-FLIGHT POST-FLIGHT	0 0	10 25	15 25	10 10	0 0	10 20	20 30	25 25	38	1 hr.(CR), 3 hrs. (FE).	600(DAK, EXP), 100(H34), 88(NEP), 3400(ARG).
15	FLIGHT ENGINEER	PRE-FLIGHT POST-FLIGHT	0 0	5 10	25 25	15 10	0 5	10 15	20 35	15 20	39	2 hrs.(FE), 2 hrs.(CR).	4390(NOR), 4300(YUK), 800(ARG).

[redacted]

APPENDIX H (Cont'd)

FOOTNOTES

(1)AS – ASW AREA,
CR – CREW REST AREA,
FD – FLIGHT DECK,
FE – FLIGHT ENGINEER AREA,
GA – GALLEY AREA,
NO – NOSE LOOKOUT AREA,
NR – ROUTINE NAVIGATOR-RADIO OPERATOR AREA,
RO – RADIO OPERATOR.

(2)ALB – ALBATROS,
ARG – ARGUS,
BEE – BEECHCRAFT,
DAK – DAKOTA,
EXP – EXPEDITER,
HAR – HARVARD,
H34 – H34,
H44 – H44,
LAN – LANCASTER,
NEP – NEPTUNE,
NOR – NORTHSTAR,
ORN – ORION,
OTT – OTTER,
SHA – SHACKLETON,
TRA – TRACKER,
TUT – TUTOR,
YUK – YUKON.

(3)OBSERVER POSITION INCLUDES NOSE AND BEAM SEARCH LOOKOUTS, AND RADIO, RADAR, ECM, JULIE, JEZEBEL OPERATORS.

(4)SEROUS OTITIS MEDIA IN THE LEFT EAR PRECLUDED MEANINGFUL POST-FLIGHT AUDIOMETRY.

(5)HEARING THRESHOLDS ARE RELATIVE TO ISO (1964) ZERO REFERENCE LEVELS.

[redacted]

APPENDIX I

SOUND PRESSURE LEVELS[1] OF THE STATIC AT THE EARS OF THE RADIO OPERATOR OF THE ARGUS AIRCRAFT. THE AMBIENT SOUND PRESSURE LEVEL AT THE RADIO OPERATOR'S LOCATION WAS 110 dB (ENGINE RPM = 2100).

OCTAVE-BAND CENTRE FREQUENCY	SOUND PRESSURE LEVEL
31.5 Hz	68 dB
63 Hz	69 dB
125 Hz	69 dB
250 Hz	72 dB
500 Hz	73 dB
1000 Hz	74 dB
2000 Hz	86 dB
4000 Hz	100 dB
8000 Hz	86 dB
16000 Hz	78 dB
OVERALL	100 dB

(1)The electrical signal (radio static) driving the Radio Operator's headset was measured and recorded during flight. The acoustical signal was later reproduced (using the same headset in the laboratory) and the sound pressure level at the entrance to the Operator's ear canal was measured using a probe microphone (see Appendix F).

[redacted]

[redacted]

APPENDIX K

VIBRATION LEVELS, ARGUS AIRCRAFT ENGINE SPEED = 2200 RPM

MEASUREMENT LOCATION	ACCELERATION, METER/SEC^2 RMS — OCTAVE-BAND CENTRE FREQUENCY 31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz
FLOOR RAIL, PILOT SEAT.	.54	.25	.14	.11	.27	.78	.31
FLIGHT DECK, CENTRE CONSOLE, ATOP AUTO PILOT.	.25	.20	.22	.20	.18	.88	.27
ROUTINE NAVIGATOR, DESK TOP.	.69	.78	.96	.54	.54	.27	.043
RADIO OPERATOR, DESK TOP.	.62	1.5	3.7	.33	.93	.47	.042
GALLEY TABLE TOP.	.27	1.0	2.5	2.5	3.0	.77	.10
STBD BUNK FRAME.	.61	1.1	7.4	1.1	.88	.27	.054
ECM OPERATOR, DESK TOP.	.54	1.1	.69	.12	.62	.30	.024
SEARCH RADAR, DESK TOP.	.88	.31	1.1	.54	.34	.14	.043
MAD OPERATOR, DESK TOP.	.25	.27	.39	.27	.27	.25	.095
PORT BEAM OBSERVER, WINDOW LEDGE.	.54	.43	.61	.54	.61	.39	.20

[redacted]

[redacted]

APPENDIX J

MULTIPLE CHOICE SPEECH INTELLIGIBILITY TEST RESULTS

	TEST SPEAKER AND OBSERVER IN ROUTINE NAV/RADIO OPERATOR AREA (SPL = 110dBC)		TEST SPEAKER AND OBSERVER IN ECM OPERATOR AREA (SPL=105dBC)	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2
SUBJECT 1	100%	89%	89%	96%
SUBJECT 2	96%	96%	96%	89%
SUBJECT 3	96%	100%	93%	100%

[redacted]

APPENDIX L

TEMPERATURE DISTRIBUTION WITHIN THE AIRCRAFT AFTER 1-1/2 HRS. OF FLIGHT I

(Dry Bulb Thermometer readings in °F, Outside Air Temperature = −31°F.)

STATION	LEVEL AT WHICH TEMPERATURE WAS RECORDED		
	FEET	WAIST	HEAD
Pilot	70	75	78
Co-pilot	71	71	72
Flight Engineer	68	68	72
Routine Navigator	42	62	68
Radio Operator	42	58	60
Radar Operator*	72	72	72
Tactical Navigator	73	73	76
Tactical Co-ordinator	71	71	74
Jezebel Operator	76	75	77
MAD/Julie Operators	72	72	75
ECM (forward)	77	76	80
ECM (aft)	75	74	78
Starboard Observer	68	66	72
Port Observer	68	66	72
Nose Observer	42	50	60

* Temperatures at this station were recorded after 5-1/2 hrs. of flight.

[redacted]

APPENDIX M

TEMPERATURE DISTRIBUTION WITHIN THE AIRCRAFT AFTER 11 HRS. OF FLIGHT I

(Dry Bulb Thermometer readings in °F, Outside Air Temperature = -22°F)

STATION	LEVEL AT WHICH TEMPERATURE WAS RECORDED		
	FEET	WAIST	HEAD
Co-pilot	60	68	68
Flight Engineer	68	72	72
Routine Navigator	32*	62	72*
Radio Operator	38	59	63
Galley Table	20*	50	64*
Bunk Area (prone posture)	76	76	76
Tactical Navigator	57	63	66
Jezebel Operator	56	64	66
MAD/Julie Operators	58	68	70
ECM Operators	38	68	68
Starboard Observer	43*	58	100*
Port Observer	50*	80	94*
Mattress over sono-buoys (prone posture)	60	60	60
Nose Observer	30	42	52

* Shows vertical temperature gradient of 40 degrees (F) or over.

[redacted]

APPENDIX N

FLIGHT STATUS OF 190 CONSECUTIVELY SCHEDULED ARGUS FLIGHTS DURING SIX MONTHS OF OPERATIONS BY 404 AND 405 MARITIME PATROL SQUADRONS (SEE REFERENCE NO. 30)

Take-off on schedule.	46%
Take-off delayed by one-half hour or more due to unserviceable equipment.	35%
Flight cancelled due to unserviceable equipment.	5%
Flight cancelled due to bad weather etc.	14%